Methane Emissions from Abandoned Coal Mines in China

A study of abandoned coal mines in Shanxi Province, China, designed to facilitate identification and development of abandoned mine methane projects, enhance knowledge of abandoned mine methane emissions, and develop methodologies to forecast emissions. For more information, visit the project website at www.chinamethane.org.

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Ruby Canyon Engineering ● University of Colorado Boulder ● Camco

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A project of the University of Colorado at Boulder's Renewable and Sustainable Energy Institute, Ruby Canyon Engineering, and Camco

Ron Collings, Ruby Canyon Engineering
Kevin L. Doran, University of Colorado Boulder
Robin Murray, Camco

RUBY CANYON ENGINEERING

camco

University of Colorado Boulder

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Executive Summary

This study is based on a detailed inventory of methane emissions from abandoned coal mines in China. The initial data collection efforts for this study focused on the eastern piedmont of the Taihang mountains in the coal-bearing region of Shanxi Province, China.

Chinese government sources state that methane emissions associated with coal production were 19 billion m3 in 2006, whereas the total methane emissions from all coal mine sources in China are estimated to contribute 730 million tonnes of CO2 equivalent to the atmosphere each year. Chinese coal production has risen from 2.380 billion tonnes in 2006 to 2.716 billion tonnes in 2008. While there are activities to capture and destroy methane from active coal mines and pre-mine drainage funded through the Clean Development Mechanism (CDM), through direct support from external organizations and agencies and through the introduction of regulations, there is dearth of information on emissions from abandoned mines and no known projects to capture and destroy the methane being emitted from this source. The reasons for this are numerous: lack of empirical data on methane being generated, ownership issues and a lack of focus on abandoned mine methane due to the range of opportunities available at active mines—under the CDM, for instance, there is currently no approved methodology for abandoned mine methane projects.

This study is designed to help redress the lack of knowledge of, and focus on, abandoned mines by producing a systematic inventory of abandoned mine methane emissions in China, with an initial focus on the coal bearing regions of Shanxi Province. There is believed to be 260 billion tonnes of coal in Shanxi Province, and the annual coal production was 0.66 billion tonnes in 2008 (representing nearly one quarter of the China total) from 2800 separate mines. The life time of an average local mine is typically 20 years.

The following was developed during the course of this study:

- A comprehensive set of government documents, both national and provincial, were accumulated and summarized regarding policies on the closure and consolidation of coal mines in China as well as policies regarding the incentives available to the coal mining industry for the capture and utilization of CMM.
- Coal characteristics relevant to methane content and production were cataloged for the various gas regions of the Qinshui coal basin.
- Specific information about the size, location, coal production, gas contents and opening and closure dates for forty-four (44) abandoned mines in the Qinshui coal basin was gathered in cooperation with the Shanxi Fenwei Energy Consulting Co. Ltd.

- An approach was developed to estimate the AMM resource available for use and the probable rate of recovery of that resource based on a combination of gas material balance, methane emission rate during mining and a decline function based on an adsorption isotherm for the relevant gas region. This methodology can be used to identify abandoned mines that may be candidates for methane capture and use projects in any coal basin by providing estimates of the remaining resource and possible methane production rates.
- The Shanxi case study found that of the 44 abandoned mines studied 36 are expected to be able to produce over 60 million m3 over a twenty year project life. The largest of these mines may produce as much as 630 million m3.
- Of the 44 mines analyzed three from different gas regions were selected for pro-forma economic analysis case studies. These studies showed that power generation projects could be economically instituted given that the current government power price incentives are obtained. It was also found that only the largest of projects would be economically viable as gas treatment and high pressure pipeline sales projects.
- An online platform was created to present the above data and analysis. The online platform, which is available at www.chinamethane.org, has three primary tools to facilitate interaction with and analysis of project data: (1) a geographic information system that presents the abandoned mine data using Google Maps API v3; (2) a relational MySQL database that enables users to interact with the abandoned mine dataset using the GIS interface, the custom charting system, or a separate search interface; and (3) a charting system that presents aggregate and mine-specific data using dynamic HTML5 charts with data pulled from the MySQL database. In addition to these tools, the platform contains reports and analysis generated throughout the project. The system uses the extensible Joomla framework for content management and administrative control. This framework allows different levels of users—e.g., administrators, registered users, etc.—to easily interact with the underlying dataset and database. It also provides an efficient and flexible backbone for tying the GIS system, MySQL database, and custom charting tool together into a unified framework.

In addition to providing a systematic, supported and transparent resource to facilitate the identification and development of abandoned mine methane projects, the study is intended to improve knowledge of abandoned mine methane emissions and methodologies to forecast these emissions, provide a template for similar work, and enable Chinese and other national authorities to better estimate methane emissions.

This sample set of forty-four abandoned coal mines (out of thousands in Shanxi province) may be emitting over 500,000,000 m^3 per year of methane or about 7,000,000 tCO2e based on this analysis. And although these represent the larger of the recently abandoned mines this large figure should warrant more aggressive investigation to assess and both mitigate as well as to utilize this greenhouse gas as clean energy fuel.

Introduction

Coalbed methane is formed during coalification, the process that transforms plant material into coal. Organic matter accumulates in swamps as lush vegetation dies and decays. As this organic matter becomes more deeply buried, the temperature and pressure increase, subjecting the organic matter to extreme conditions that transform it into coal, as well as byproducts including methane, carbon dioxide, nitrogen, and water; with methane being the predominate gas constituent. The gasses contained in the coal are commonly referred to as coalbed methane (CBM) or coal seam gas.

The methane is trapped in coal seams through physical adsorption. The amount of methane held in the coal is a function of temperature and pressure. The rate at which the gas can be released is a function of the permeability of the coal to the flow of gas. CBM can be produced through wellbores by initiating flow through the coal by establishing a pressure differential between the wellbore and coal seam. It can also be liberated through mining activities which reduces the pressure and also increases the permeability because of the fracturing of the coal and surrounding rock coal caused by removal of the coal.

The release of methane during mining is a safety problem worldwide and is dealt with through dilution by ventilating the mine workings with fresh air, high concentration methane drainage within the mine workings and sometimes through pre-drainage of the gas through boreholes prior to mining. As active mining stops, the mine's gas production decreases, but the methane liberation does not stop completely. Following an initial rapid decline, abandoned mines can liberate methane at a near-steady rate over many years. The gas migrates to the atmosphere through various conduits, such as poorly sealed shafts and boreholes and as diffuse emissions through cracks and fissures in the strata overlying the coal mine.

Chinese government sources state that methane emissions associated with coal production were 19 billion m3 in 2006, whereas the total methane emissions from all coal mine sources in China are estimated to contribute 730 million tonnes of CO2 equivalent to the atmosphere each year. Chinese coal production has risen from 2.380 billion tonnes in 2006 to 2.716 billion tonnes in 2008. While there are activities to capture and destroy methane from active coal mines and pre-mine drainage funded through the Clean Development Mechanism (CDM), through direct support from external organizations and agencies and through the introduction of regulations, there is dearth of information on emissions from abandoned mines and no known projects to capture and destroy the methane being emitted from this source. The reasons for this are numerous: lack of empirical data on methane being generated, ownership issues and a lack of focus on abandoned mine methane due to the range of opportunities available at active mines—under the CDM, for instance, there is currently no approved methodology for abandoned mine methane projects.

The determination of methane emissions from abandoned coal mines has a high degree of uncertainty because of the diffuse nature of the emissions. Occasionally, open boreholes vent methane to the atmosphere. In this case the flow rate and concentration can be monitored; however this is rarely the case.

The U.S. Environmental Protection Agency issued a report in April 2004 that provided a methodology for estimating the methane emissions from abandoned coal mines in the United States[1]. This methodology combined physical characteristics of coals in various coal mining districts with known information about the abandoned mines. A similar but modified approach is used in the evaluation of the mines identified in this study.

This result of this study will help redress the lack of knowledge of, and focus on, abandoned mines through producing a systematic inventory of abandoned mine methane emissions for a group of mines in a coal bearing region of Shanxi Province. There is believed to be 260 billion tonnes of coal in Shanxi Province, and the annual coal production was 0.66 billion tonnes in 2008 (representing nearly one quarter of the China total) from 2800 separate mines. This investigation has selected 44 of the several hundred abandoned coal mines in the area in order to develop a methodology that can be broadly applied to a broader population of mines, not only in Shanxi province but elsewhere that has similar data sets.

In addition to providing a systematic, supported and transparent resource to facilitate the identification and development of abandoned mine methane projects the work will improve knowledge of abandoned mine methane emissions and methodologies to forecast these emissions, will provide a template for similar work in other Chinese provinces and regions and will allow Chinese authorities to better estimate abandoned mine methane emissions nationwide.

1. Goals and Objectives of the Study

- Learn how to access information on abandoned coal mines
  - Determine how and where to obtain data on abandoned mines
  - Determine what data is available for those mines
- Develop an approach to estimate the methane emissions through time for a sample set of abandoned mines based on the data available
- Estimate the volume of the methane resource by mine and provide an estimate of the probable rate of recovery of that resource
- Develop high level case studies for three potential projects and to present these opportunities as case studies at regional or national mine methane forums to encourage private and public sector action to reduce emissions.
- Assist CMAs and third party developers in identifying viable methane mitigation opportunities by listing local, provincial and nationwide incentives pertaining to the capture of abandoned mine methane
- Identify and catalogue some of the non-technical barriers to developing abandoned mine methane projects in the regions studied. These include national and local regulations and enforcement mechanisms, ownership, finance, technology and access to markets for the methane captured.

[1] Methane Emissions From Abandoned Coal Mines in the United States: Emission Inventory Methodology and 1990 – 2002 Emissions Estimates, US EPA, Air and Radiation 6202J, EPA 430-R-04-001, May 2004

- Aid project developers in identifying potential AMM project sites by utilizing Geographical Information System (GIS) technology to build an interactive online database. This GIS application will allow project proponents to identify potential projects not only by probable methane reserves but also by favorable access to necessary infrastructure such as the existing power grid, pipelines, roads and towns.
- Present the results of the study to industry stake holders through conferences and publications.

2. China's General Coal Mining Policies

The Five-year Plan for the Development of Coal Sector in China, released by NDRC in Jan 2007, draws a prospective roadmap for China's coal sector. The plan concludes that, coal, accounting for 2/3 of nationwide energy consumption, plays a strategic role in the national economy for the long run. It is expected that demand for coal will continue its recent rapid growth.

In the light of the Plan, China aims to build up a modernized coal industry system based on a series of practices: consolidation of coal enterprises, improved mechanization, innovation in technologies, organizational structure optimization, rational development, work safety, cost-efficient energy utilization and protection of the environment. Efforts will be focused on the merger and acquisition for the small-sized coalmines in the bid to rationalize the resource development with clean and safer production.

Industrial upgrading based on science and technology is key for the coal sector. The 11th Five-year Plan indicates the government aims to transition to the use of modern technology in coal mines, using coal excavation mechanization at over 95% of large-scale coal mines, 80% at the medium-scale coal mines, and 40% at smaller coal mines. To achieve this goal, China further enlarged technology investment, promoted scientific research to tackle key issues in manufacturing efficient coal mining technologies, including open-cast mining equipment, large-scale transportation equipment, coal washing equipment and coal mine methane recovery and utilization.

According to the Plan, China will create six to eight coal mining groups with the capacity to produce 100 million tonnes of coal per annum, as well as another eight to ten coal groups with an annual production of 50 million tonnes each. China will build 13 large coalmine bases, with coal production of 2.2 billion tonnes per annum, a share of about 86% of the total national production.

The major tasks for the development of coal sector set by the Plan include:

- To optimize the geologic distribution of coal resource development
- To build up large-scaled coalmine bases
- To encourage very large coal-based conglomerates
- To adjust and upgrade small-sized coalmines
- To push forward innovation in sciences and technology
- To drive up the process of demonstration projects on coal chemicals
- To upgrade the level of coalmine safety

- To construct the new mine areas focusing on energy efficiency and environmental protection
- To expand the transportation capacity of railways and coal ports

In November 2007, China issued the first national industrial policy for coal sector. The policy increases the coal industrial entry requirements and states that China will not approve new projects with an annual production of less than 300,000 tonnes during the 11th five-year plan period. In addition, in coal-abundant provinces such as Shanxi, Shaanxi and the Inner Mongolia Autonomous Region, the designed capacities for newly constructed, reconstructed, or expanded projects are required to be no less than 1.2 million tonnes per annum.

The new policy encourages breaking through the geographical and ownership limitations to develop large-scale coal firms by combining, merging and reconstruction of small- and medium-size coal firms. With regards to rationality in development and safety, the new policy calls to establish and improve necessary systems including ventilation, methane drainage, fireproof, dustproof, and flood proof. Great importance is attached on the establishment of methane drainage, monitoring and control system.

3. China's Coal Mine Closure and Consolidation Policies

3.1 National Policies

The coal mining sector in China has undergone substantial re-structuring in recent years and this process is ongoing. Mine closure is an inevitable consequence of changing from a command and control system to a market system. Mines also have a finite life due to depletion of coal reserves.

About 60 thousand small-scale coal mines have been closed since 1997. The State Council has approved to close 65 major large-scale state-owned coal mines by the end of 2000, many of these coal mines are rich gas mines. In 2005, China had more than 24,000 small coal mines with the annual production output ranging from 10,000 tons to 30,000 tons, which account for 70 percent of the country's number of coal mining ventures. The small coal mines have caused not only grave resource waste with a low recovery rate, which is averaged between 10 percent to 15 percent, but also serious pollution and higher incidence of major accidents, posing a long-standing problem endangering safety at coal mines in China.

Over the past years, numerous coal mines have been policy-mandated closed and abandoned for the sake of work safety and resource optimization. The key policies are listed in Table 1, 3, and 4.

Table 1: List of key regulations and policies at national level

Name	Effective Date	Issuing Authority
Plans for the Closure of Small Coal Mines during the Last Three Years of the 11th Five-Year Plan Period	Oct 2008	NDRC, the Energy Department, the State Administration of Work Safety, the State Administration of Coal Mine Safety
Notice on Strengthening the Management of Abandoned Mines	Sep 2008	NDRC, The Ministry of Land and Resources, the Administration of Work Safety, the Ministry of Environmental Protection

Notice regarding Strengthening the Rectification and Closure of Coal Mines	Sep 2006	12 ministries and departments, including NDRC, the Administration of Work Safety, the Administration of Coal Mine Safety, the Ministry of Land and Resources, and etc.
Comments on the Development of the Three-year Plan for Rectification and Closure of Coal Mines	May 2006	Work Safety Committee Office of the State Council
Comments on Strengthening the Management of Coal Mine Safety and Optimizing the Structure of Coal Industry	Mar 2006	8 ministries and departments, including the Administration of Work Safety, the Administration of Coal Mine Safety, the Ministry of Land and Resources, and etc.
Notice on Closing Unsafe and Illegal Coal Mines	Aug 2005	The State Council

The strategy for the treatment of small coal mines has been changing from shutting down unsafe small coal mines toward phasing out outdated technologies, policy-mandated closure and resource integration.

As early as 2005, based on the target set by the State Council to tackle small coal mine related problems within three years, the State Administration of Work Safety and the State Administration of Coal Mine Safety has put forward a Three-step Strategy "Rectification and Closure of Small Coal Mines– Resource Integration and Technology Improvement – Management of Major Coal Mines".

In August 2005, the State Council issued the Notice on Closing Unsafe and Illegal Coal Mines, which required that, coal mining activities, which could not meet work safety requirements, or did not obtain all legally required permits and approvals, or did not equip with coal mine methane monitoring and drainage system, or did not through the final completion acceptance for the work safety equipment, must be stopped for rectification, and coal mines that still fail to meet safety requirements after rectification must be resolutely closed by the local government. The Notice also requires that relevant authorities at local level should release the list of closed coal mines.

To further optimize coal industrial structure, eight ministries and departments, including the Administration of Work Safety, the Administration of Coal Mine Safety, and the Ministry of Land and Resources, jointly issued in March 2006 the Comments and Opinions on Strengthening the Management of Coal Mine Safety and Optimizing the Coal Industrial Structure, and clearly stated that China is going to close all small coal mines with an annual production capacity of 30,000 tonnes or less by the end of 2007. In addition, according to the Notice, China would streamline the coal mining sector to improve work safety and encourage large coal mining firms to merge with smaller ones, but required that the combined production capacity for individual coal mine located in Shanxi province should be no less than 300,000 tonnes per annum.

At the same time, to facilitate the implementation of the Three-step Strategy, in May 2006, the Work Safety Committee Office of the State Council issued the Guidelines for the Development of the Three-year Plan for the Rectification and Closure of Coal Mines. Based on the Plans submitted by local governments, the Work Safety Committee set the target to shut down 9887 small coal mines in three periods:

- Phase I (July 2005 – June 2006): to close 5026 unsafe and illegal small coal mines
- Phase II (July 2006 – June 2007): to close 2652 small coal mines, which have caused severe damage to natural resources and environmental pollution or fall short of industrial policies
- Phase III (July 2007 – June 2008): to close 2209 small coal mines

By the end of 2007 China has closed 11,155 small coal mines, which accounts for 45% of the total number at the beginning of 2005, and 8,821 coal mines from 20 provinces, autonomous regions and municipalities have been combined into 3,747 larger coal mines.

In October 2008, the National Development and Reform Commission, the Energy Department, the State Administration of Work Safety, and the State Administration of Coal Mine Safety, issued a Plan for the Closure of Small Coal Mines during the Last Three Years of the 11th Five-Year Plan Period. According to the Plan, China pledges to further cut down another 4000 small coal mines, where 2500 small coal mine will be fully closed and the remaining 1500 small coal mines must go through expansion and reform or will be merged by larger coal mines. The ultimate goal of Chinese government is to control the number of small coal mines with annual production capacity less than 300,000 tonnes to be less than 10,000 by the end of 2010. The target for the closure of small coal mines has been broken down into every province / region / municipal city. The following table presents the targets for Shanxi and Hebei province to close small coal mines in the last three years of the 11th five-year plan period.

Table 2: Targets to close small coal mines in the last three years of the 11th five-year plan period

	Number of existing small coal mines	Number of small coal mines to be closed	Number of small coal mines to be merged with large coal mines	Number of remaining small coal mines by the end of 2010
China	14069	2501	1616	9952
Shanxi	1702	500	102	1100

In January 2009, the director of the State Administration of Coal Mine Safety, Mr. Zhao Tiechui, announced that China has further closed another 1,054 small coal mines which failed to meet the work safety requirements or were inconsistent with industrial policies.

In September 2008, the National Development and Reform Commission, the Ministry of Land and Resources, the Ministry of Environmental Protection, and the State Administration of Work Safety have jointly issued an Notice on Strengthening the Treatment of Abandoned Mines, which requires that the local government at various levels to conduct the research on the abandoned mines within its jurisdiction and to develop relevant planning for the treatment of abandoned mines. According to the Notice, both the research and planning for treatment are required to be completed by the first quarter of 2009.

3.2 Local Policies

The 11th Five-year Plan of Shanxi for the Coal Sector, issued by the Shanxi provincial government in July 2007, pointed out that the local government has closed 6,799 unsafe or illegal small coal mines by the end of 2005 and is planning to keep the number of coal mines below 2,500 by 2010 and 2,000 by 2015. According to the Plan, in 2005 there were in total 4,278 coal mines with a verified production capacity of 592 million tonnes per annum in Shanxi.

Table 3: List of key regulations and policies in Shanxi

Name	Effective Date	Issuing Authority
Plan for the Restructuring and Revitalization of Coal Sector in Shanxi (2009-2011)	Apr 2009	Shanxi Provincial Government
Notice on Further Accelerating the Merger and Acquisition of Coal Enterprises	Apr 2009	Shanxi Provincial Government
Notice on Carrying out Special Actions to Crack down on Illegal Mining	Jun 2008	Shanxi Provincial Government
The 11th Five-year Plan of Shanxi for the Coal Sector (20062010)	Jul 2007	Shanxi Provincial Government
Notice on Strengthening the Rectification and Closure of Coal Mines	Nov 2006	Shanxi Provincial Government
Implementation Measures for the Merger and Acquisition of Coal Enterprises	Apr 2009	Tiayuan City Government

In November 2006, the Shanxi provincial government issued the Notice on Strengthening the Rectification and Closure of Coal Mines, which stated that the local government had successfully achieved the target set by the State Administration of Coal Mine Safety to close 1,156 coal mines during the July 2005 through June 2006 period, and planned to further close another 600 coal mines during the July 2006 through June 2007 period and another 500 coal mines during the July 2007 through June 2008 period. The Notice also required that coal mines located in the 60 major coal bearing counties but with an annual production capacity of 90,000 tonnes or less must be closed by the end of 2007.

Additionally, the Shanxi provincial government specified, in the Notice on Carrying out Special Actions to Crack down on Illegal Mining issued in June 2008, ten types of coal mines that must be immediately closed. At the same time, the Plan for the Closure of Small Coal Mines during the Last Three Years of the 11th Five-Year Plan Period set a target for Shanxi to further close another 500 small coal mines in the last three years of the 11th five-year plan period.

The ongoing financial crisis has great impact on coal industry in Shanxi province, while it also provides opportunity for the readjustment and upgrading of the industry. To actively react to global financial crisis and set a solid basis for the coal sector development in the forthcoming 12th Five-year Plan period, the Shanxi provincial government newly issued in April 2009 the Plan for the Restructuring and Revitalization of Coal Sector in Shanxi. One of the top priorities of the Plan delivered by the government is designed to press ahead with the closure of small coal mines and the consolidation of the coal industry in the province. According to the Plan, there were 2,598 coal mines in the end of 2008, but more than 80% of these coal mines are small coal mines with an annual production capacity of 300,000 tonnes. It is the vision of the Plan that the total coal mines will be reduced to 1,000 by 2011, and 800 by 2015.

In order to better achieve the stringent target set in the Plan, several local governments at city or county levels in Shanxi has considered providing financial incentives for counties that complete required targets for the closure of small coal mines within timeline. Taiyuan government sets aside RMB 416 million to prompt the closure of 50 small coal mines in 2009 and offers an award of RMB 5 million to the county government for the close of each coal mine as schedule.

4. National Coal Mine Methane Extraction and Utilization Policies

4.1 Mandatory Policies for CMM Extraction and Utilization

Table 4: List of key policies and regulations

Name	Effective Date	Issuing Authority
Emission Standard of CBM/CMM	Jul 2008	Ministry of Environmental Protection
Opinions on Speeding up CBM/CMM Extraction and Utilization	Jun 2006	The State Council

To address coal mine safety, in June 2006 the State Council issued Opinions on Speeding up CBM/CMM Extraction and Utilization, which clarified the guiding principle of gas extraction prior to coalmining, integrated with gas control and utilization. The policy requires that local land and planning authorities ensure that coal mines implement a safety first approach, focusing on prevention, safety standards and oversight by the government and the use of technology. Key aspects of this policy are:

- Coal mine methane must be drained first, prior to coal mining (if gas content is above a specified level);
- Coal mines must implement CMM measurement and monitoring activities;
- Coal production activity is not allowed without a CMM drainage system; if there are significant problems caused by coal mine methane, mining activity must be suspended; and
- Coal mine owners and operators have legal responsibilities to ensure that these standards are followed.

In addition to this policy, in April 2008 the Ministry of Environmental Protection issued an Emission Standard of CBM/CMM, which became effective on 1 July 2008 for new coal mines and surface drainage systems, and will become effective on 1 January 2010 for existing mines/systems. This new standard dictates the following:

- CBM drainage systems are prohibited from emitting CBM;
- CMM drainage systems with the methane concentration of 30% or above are prohibited from emitting the methane (e.g., they must either use or flare the gas); and

- If the methane concentration is less than 30%, the methane is allowed to be released.

4.2 Incentive Policies for CMM Recovery and Utilization

Table 5: List of key policies and regulations

Name	Effective Date	Issuing Authority
Implementing Opinions on Subsidizing CBM/CMM Development and Utilization Enterprises	Apr 2007	Ministry of Finance
Implementing Opinions on Power Generation using CMM	Apr 2007	NDRC
Notice on CBM/CMM Price Management	Apr 2007	NDRC
The 11th Five-Year Plan for CBM/CMM Development and Utilization	Jun 2006	NDRC

The 11th Five-Year Plan for CBM/CMM Development and Utilization (NDRC, June 2006) proposes (among other objectives) that by 2010, the national CBM/CMM output should reach 10 billion cubic meters (bcm) via the establishment of a formal CBM/CMM industry.

The Plan delivered a big picture of the CMM drainage and utilization in China during the 11th five-year period. The Plan lays the stress of CMM drainage and utilization on the coal mine safety, and calls for efforts to establish a complete and standard regulatory system, to break through technical bottlenecks, to carry out demonstration projects, and to increase the drainage and utilization rate.

In addition, the Plan put forward the goal that the national CMM drainage and utilization is expected to reach 5 bcm and 3bcm, respectively, by 2010. The key provinces and municipalities directly under the Central Government for large-scale CMM drainage and utilization include Shanxi, Liaoning, Anhui, Henan, Chongqing, Sichuan, Guizhou, Shaanxi, and Ningxia.

Table 6: Plans for CMM drainage and utilization during the 11th five-year plan period Unit: 10,000 m3

	2006		2007		2008		2009		2010	
	Drain	Utilize	Drain	Utilize	Drain	Utilize	Drain	Utilize	Drain	Utilize
National	261651	100349	346591	175889	387006	220530	458183	257654	528395	320081
Shanxi	59820	34562	104880	71748	107995	76204	127840	80112	151570	120111

To aid in implementing this goal and address market barriers, in April 2007 NDRC issued a Notice on CBM/CMM Price Management. It specifies that the price of gas that is not distributed via city pipeline networks can be determined freely through negotiations, while the price of gas distributed via city pipeline networks and operations under government control should be determined according to its heating value (compared to substitute fuels such as natural gas, coal gas and liquefied gas). Also in the same month, NDRC issued a Notice on Implementing Opinions on Power Generation using CMM. This encourages the deployment of power generation projects with CBM/CMM. The notice requires that electricity generated by CBM/CMM power plants should be given priority by grid operators who should purchase surplus electricity at a subsidized price, as specified by NDRC in the Trial Management Method for Electricity Prices and Sharing Expenses for Electricity Generated with Renewable Energy. CBM/CMM power plant owners were also exempted from market price competition and do not undertake any responsibilities for grid stability.

At the same time, in April 2007, the Ministry of Finance issued Implementing Opinions on Subsidizing CBM/CMM Development and Utilization Enterprises whereby any enterprise engaged in CBM/CMM extraction within China is entitled to financial subsidies, if it is used on site or marketed for residential use or as a chemical feedstock. CBM/CMM used to generate power does not benefit from this subsidy. Further, CMM power generation projects listed in the Catalogue of Comprehensive Utilization of Resources (2003 revision) are eligible for certain preferences. Power authorities will grant enterprises co-generating electricity and heat from CBM/CMM a grid connection if the individual units have an installed capacity of above 500 kW and meet required standards. They are exempt from paying the connection fee normally charged to small-scale, coal-fired power plants; they are excluded from quotas under the national distribution plan; and they benefit from priority electricity sales to the grid at wholesale prices, or even at higher prices if approved by the provincial authorities. Those with an installed capacity of 1.2 MW or less are not required to support the grid by load following. Plants above this capacity can deliver their full output during periods of peak demand, but will never be required to drop below 85% output.

In addition to the previous policies, the Chinese government has developed a number of supporting policies to promote CMM recovery and utilization. They are summarized as follows:

- Under the National Land Transfer Policy, land use priority is given to CMM recovery and utilization projects;
- Coal mine companies with CMM drainage and recovery systems are allowed to use production safety funds to invest in CMM drainage and utilization;
- Governments at all levels are encouraged to provide discounted loans or grants to CMM projects;
- The value-added tax levied from coal mines which recover and utilize CMM is returned to the coal mine operators (returned taxes are to be used in R&D and investment in coal mine for enlarged production);
- No income tax shall be levied for enterprises which are developing technologies for CMM recovery and utilization;

4.3 Barriers to Coal Mine Methane Utilization

According to desktop research and literature review, we concluded five major non-technical barriers block CBM/CMM exploration and utilization in China. These barriers include aspects of policy, system, market environment, investment, personnel.

1. Lack of strong policy support. China is on the initial stage of coal bed methane industry, especially for abandoned mine methane develop, therefore, government needs to set up more rigorous policy support to encourage its development.

2. CBM development rights and coal mining rights over lap. According to Chinese Mineral Resources Law, coal firms who obtain coal mining right in a CBM area are not allowed to conduct surface CBM exploitation. Separation of these two rights constrains CBM development.
3. CBM utilization is restricted due to some reasons: no affiliated transit pipeline in the CBM exploitation area, which makes it difficult to get into market and increases cost; on-grid price for gas power generation is too low to get profit for power generation company; lack of safety management criterion, lack of standard and supervision regulations of CMM utilization; lack of concerns on environmental pollution.
4. CMM needs large capital investment; therefore, more investment channels need to be opened.
5. CBM/CMM prospecting and exploitation personnel are from the coal, oil and geological sectors with different background and skills. Professional technical training and management training needs to be provided to these technical teams.

4.4 Local Coal Mine Methane Policies

The CBM reserves of Shanxi amounts to 10 trillion cubic meters, accounting for 1/3 of the total CBM reserves in China. Five of six major coal mines (except Datong Coal Mine) in Shanxi are all identified to be gassy mines, where the Qinshui coal mine and Hedong Coal mine with CBM reserves of 6.85 trillion m3 and 2.84 trillion m3, respectively, rank top two. The reserves of these two mines account for 93.26 of the total CBM reserves of Shanxi province.

The 11th Five-year Plan of Shanxi for the CBM/Natural Gas Sector describes the prospects for the development of CBM/natural gas sector in Shanxi. It is reported that methane emissions associated with coal production was about 6 billion m^3 every year in Shanxi, whereas the CBM/CMM utilization was less than 0.5 billion m3 every year, only 1/12 of the emission amount.

Table 7: List of key policies and regulations in Shanxi

Name	Effective Date	Issuing Authority
The 11th Five-year Plan of Shanxi for the CBM/Natural Gas Sector	Mar 2007	Shanxi NDRC

Based on the market research, the demand for CBM/CMM is estimated to be 5.05 billion m^3 by 2010 and 7.2 billion m^3 by 2020. During the 11th five-year period, Shanxi is planning to develop four CBM/CMM bases including Qinnan, Yangquan, Daning-Jixian, and Baode, with expected annual CBM/CMM drainage and utilization volume to be 6 billion m^3 and 5 billion m^3 by 2010, respectively. The Plan specifics that, during the 11th five-year plan period, Shanxi will invest RMB 11 billion for surface CBM extraction with expected annual output of 4.5 billion m3 and RMB 980 million for underground CMM drainage with expected annual output of 1.55 billion m3. In addition, the local government is proposing to construct 7 new gas pipeline networks with a total length of over 2000km.

Yangquan Mining Group has the first AMM scheme in China at their #4 mine. Preliminary studies are underway. According to the Plan, the Group is going to further invest RMB 100 million for AMM project during the 11th five-year period and aims to realize an annual AMM output of 50 million m3 by 2010.

5. Selection of the Area of Study

The greater Qinshui coal basin of Shanxi province was selected because:

- Most of the coal mined is high gas content anthracite and coking coal
- There has been a long history of coal mining and hence a large number of abandoned mines
- There is a high concentration of coalmines.
- It has numerous active mine methane capture and utilization projects which could provide operational expertise for AMM projects
- It has an active CBM industry so an experienced drilling industry is present
- The coal is known to have relatively good permeability for such high quality hard coal
- It has a fairly well established gas distribution infrastructure
- The Mayor of the prefecture city of Jincheng had expressed significant interest in the potential of AMM projects in the city area

6. Analysis Approach and Data Acquisition

Our approach to estimating the methane resource available for use and probable rate of recovery of that resource is based on a combination of gas material balance and emission rate calculations. The material balance calculations are based on:

1. Original volume of methane in place (OMIP)
2. The amount of methane liberated during active mining (MLM)
3. The amount of gas emitted to the atmosphere post mining (during abandonment) to the present time (MEPM)

So the estimated volume of methane resource remaining in the system (V_{MR}, m^3) is

V_{MR} = OMIP – MLM – MEPM

In order to perform the necessary calculations the following data is needed

Regional data:

- Percent methane in the coal gas (%CH_4)
- Langmuir volume (V_L, m3/tonne of coal)
- Langmuir pressure (P_L, MPa)
- The total coal thickness (Including the mined seam) in the region within 160 to 200 meters above and 40 to 70 meters below the mined seam (H_{TC}, m)

Mine specific data:

- The thickness of the mined seam (H_{MS}, m)
- Year of initial coal production
- Year of mine closure

- Mined area (A, m^2)
- Total coal produced over the life of the mine (C_R, tonne)
- Original gas content of the coal (GC, m^3/tonne)
- Geographic location of the shaft

The Regional data was obtained from the reference book "Shanxi CBM Resources Evaluation, Development and Utilization" (Shanxi CBM Industrial Association and Shanxi Fenwei Energy Consulting CO, Ltd., 2007).

The mine specific data was obtained from various government offices by Shanxi Fenwei Energy Consulting Co, Ltd.

6.1 Original Methane In-Place

The parameters used to determine this value are

- The total coal thickness within 160 to 200 meters above and 40 to 70 meters below the mined seam. Methane contained in coals within this zone may contribute to mine emissions where longwall mining is performed (H_{TC}, m)
- Mining area. This is determined as the mine boundary upon completion of mining (A, m^2)
- Gas content expressed as normal (standard) cubic meters of gas adsorbed within one tonne of coal. This is determined through an experimental process (GC, m^3/tonne)
- Percent methane in the coal seam gas (%CH_4)

$OMIP = H_{TC} \times A \times GC \times \%CH_4$

6.2 Methane Liberated During Mining

The amount of methane liberated during mining includes methane ventilated and drained from the mine during operations. This includes methane contained in the coal that was removed as well as methane that entered the mine workings from above and below the mined seam. This is generally a measured value and is often reported as "specific" (or "relative") emissions which is a function of coal production.

- Specific emissions (SE, m^3/tonne of coal mined)
- Tonne of coal mined over the life of the mine or coal recovered (C_R, tonne)

$MLM = C_R \times SE$

If a credible value of specific emissions is not available an empirical relationship between the total coal thickness (H_{TC}), the thickness of the mined seam (H_{MS}) and the original gas content can be used to estimate the specific emissions.

$SE = GC \times (1.5 + LN(H_{TC} / H_{MS}))$

This relationship takes into account the diminishing contribution of gas from coal remote from the mined seam.

6.3 Methane Emitted Post Mining

This is the volume of methane that is estimated to have been emitted to the atmosphere after mine closure. This is a function of the average methane emission rate over the life of the mine, the adsorption pressure at closure and the time since closure. A decay function was generated based on the adsorption isotherm of the coal.

6.4 Average Emission Rate

- Average emission rate (ER_{AVG}, m^3/day)
- Days of operation (T_{OP}, days)

$ER_{avg} = MLM/T_{OP}$

6.5 Adsorption Pressure

Knowing the adsorption isotherm of a coal; that is the methane storage capacity of the coal as a function of pressure, allows the calculation of the adsorption pressure if the volume of methane and mass of coal remaining in the system at closure has been determined.

- Methane at abandonment (V_{MA}, m^3)

$V_{MA} = OMIP – GLM$

- Coal remaining at abandonment (C_{RIP}, tonnes)
- Density of coal (C_{DEN}, tonne/m^3)

$C_{RIP} = H_{TC} \text{ x } A \text{ x } C_{DEN} - C_R$

- Adsorption pressure at abandonment (P_{AA}, MPa)
- Langmuir Pressure, experimentally derived (P_L, MPa)
- Langmuir Volume, experimentally derived (V_L, m3/tonne of coal)

$P_{AA} = V_{MA} \text{ x } P_L / (V_L \text{ x } C_{RIP} - V_{MA})$

6.6 Decay Function

Methane flow through coal can be approximated by general rules of fluid flow through porous media. For linear flow of an incompressible liquid, Darcy's law is of the form

$q = (kA/\mu)(dp/dl)$

- q = volumetric rate in cm3/sec
- k = permeability in Darcys
- A = the cross-sectional area perpendicular to flow in cm2
- µ = the viscosity of the fluid in centipoises
- dp/dl = the change in pressure per unit length or pressure gradient in atm/cm

The form of Darcy's law must be modified for gases, for which both viscosity and volume are functions of pressure. Key parameters for determining gas flow through a porous medium such as a coal mine include the following:

- Permeability, k, a property of the porous media (coal cleat system) plays a major role in the rate at which gas can flow from the coal into the void space of the abandoned mine. Unfortunately, measurements of the absolute permeability of coal are scarce.
- The area, A, across which gas moves from the coal into the void space can be very large because of the large areas of exposed coal in an underground mine. Determining the coal's surface area in an abandoned mine is not feasible.
- The partial pressure of methane in the mine void remains at or near atmospheric. The pressure gradient from the coal to the void space of the mine decreases over time as the gas is released and the pressure in the coal seam is reduced. As a result, the emissions rate from an abandoned mine decreases over time.

Gas production from oil and gas wells is predicted using Darcy's Law together with material balance equations. In this context, the well acts as a material sink whose rate of withdrawal (q) is a function of the difference between a specified pressure at the well, (Pw), and the pressure at some outside boundary of the gas reservoir (Pr). For a gas, this function takes the following form:

$q = PI\ (Pw^2 - Pr^2)^n$

- q = volumetric rate of gas production
- Pw = pressure at the well
- Pr = pressure of the gas reservoir
- PI = Productivity Index
- n = empirically derived exponent that accounts for turbulent flow in this case all flow is laminar so n = 1

This equation is Darcy's law, modified for a gas and combining the permeability of the rock, the viscosity of the gas, the geometry and configuration of the pressure sink and outside gas reservoir, and the thickness of the flow unit into the productivity index (PI) term.

By analogy, the coal mine and its connection to the atmosphere (via the vent shaft or overburden fracture conduit) acts as the wellbore, and the coal within and peripheral to the mine is the reservoir of the stored methane. The PI can be considered a constant at the low pressures involved in an abandoned mine system.

To determine the PI of a coal mine the above equations can be reconfigured to:

$PI = ER_{avg} / P_{AA}^2$

P_{AA} is the methane adsorption pressure at abandonment. The Pw term is assumed zero because the partial pressure of methane in the atmosphere is essentially zero.

Assuming PI to be constant we can now calculate the emission rate through time for the mine

- Methane remaining at year (i), (V_{MA}(i), m^3)
- Methane adsorption pressure at year (i), (P_{AA}(i), MPa)
- Emission rate for year (i), (ER(i), m^3/year)

$V_{MA}(i) = V_{MA}(i-1) – ER(i-1)$

$P_{AA}(i) = V_{MA}(i) \times P_L / (V_L \times C_{RIP} - V_{MA}(i))$

$ER(i) = PI \times P_{AA}(i)^2$

This results in a decay function (or decline curve) as shown in **Figure 1**.

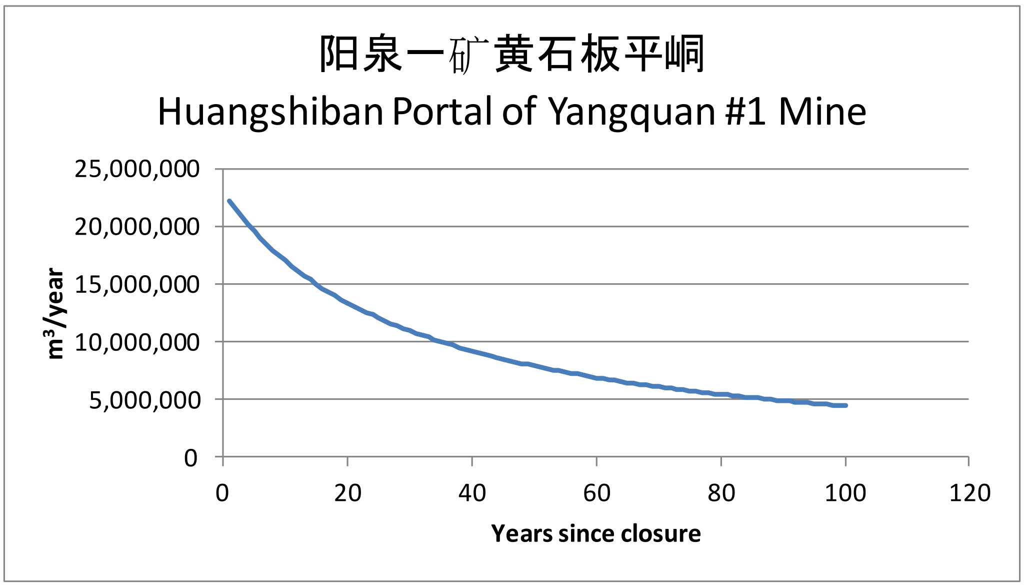


Figure 1: Methane emission rate decline after closure

7. Gas Region Specific Data

There are six coalfields in Shanxi province; Datong, Ningwu, Hedong, Xishan, Huozhou and Qinshui. Mining in the Datong and Ningwu is primarily in the low gas content Datong group which consists of Mid Jurassic and Lower Tertiary sediments. Mining in the Hedong, Xishan, Huoxi and Qinshui coalfields is primarily in the high gas content coals of the Taiyuan group and Shanxi group of Permo-Carboniferous age. The mines selected for this study are within the Hedong, Huozhou, Xishan and Qinshui coalfields.

Within each coalfield there are discreet gas regions defined by structural lines such as fault zones and anticlines. The gas bearing characteristics and the thickness of the coal measures vary by region and are described in the reference book “Shanxi CBM Resources Evaluation, Development and Utilization” as previously cited.

Figure 2 shows the coal fields and gassy mines (relative emissions greater than 10 m^3/tonne mined) of Shanxi province. The mining is restricted to the margins of the coal basins where the coal is relatively shallow. Most of the mines are less than 600 meters deep with some between 600 and 1000 meters. Basin center depths to coal range up to 2,000 meters.

Because the total coal thickness in each gas region contributes to the mines gas emissions the seam specific values for gas composition and adsorption characteristics were averaged for use in the calculations.

7.1 Qinshui Coalfield

The Qinshiu coalfield is the largest structural coal basin in southeastern Shanxi province and includes the Dongshe, Jiebei, Lindong, Shouping, Heshun, Wuxiang, Huodong, and Qinnan gas regions (**Figure 3**). Mines in the Shouping and Qinnan regions were targeted because of the high density of gassy mines in the area as shown in **Figure 2**. Anthracite is the primary coal type produced. The Shouping and Qinnan gas regions have similar coal measure thickness and gas composition but different adsorption characteristics

7.2 Shouping Gas Region

The mines selected in the Shouping gas region are all within the prefecture city of Yangquan, a highly developed coal mining area in the northeast of the Qinshui coal basin. This area has numerous active mine methane drainage projects underway. Of the eleven mines selected in the Shouping gas region six mined the #3 seam, two mined the #12 seam and three mined the #15 seam.

Gas Composition

Shouping and Qinnan Gas Regions			
	#3 Seam	#15 Seam	Average
CH4	88.58	89.44	89.01
CO2	3.48	3.00	3.24
N2	7.94	7.56	7.75
C2+	0	0	0
Total	100.00	100.00	100.00

Coal Thickness

Qinnan and Shouping Gas Regions, meters				
	Seam No.	Low	High	Average
Shanxi Fm	1	0	2.28	1.2
	2	0.35	1.95	1
	3	0.2	4.7	1.9
	3-1	0	4.3	1.65
	5	0	3.7	0.65
	6	0	3.85	1.2

Taiyuan Fm	7	0	1.24	0.7
	8	0	4.24	1.8
	9	0	5.73	2.1
	11	0.13	0.9	0.4
	12	0	2.86	1.2
	13	0	1	0.6
	15	5.2	9.5	6.5
	16	0	3.55	0.82
Total		5.88	49.8	21.72

Adsorption Characteristics

Shouping and Xingjiashe Gas Regions		
Seam No.	V_L m^3/t	P_L MPa
3	31.28	1.85
3	37.16	2.78
3	37.10	2.78
3	24.81	1.93
Average #3	**32.59**	**2.34**
Std Dev #3	**5.09**	**0.45**
15	29.45	1.00
15	32.67	1.98
15	31.54	2.21
15	36.11	2.22
15	41.29	1.25
Average #15	**34.21**	**1.73**
Std Dev #15	**4.14**	**0.51**
Average All	**33.49**	**2.00**
Std Dev All	**4.94**	**0.60**

7.3 Qinnan Gas Region

The mines selected in the Qinnan gas region are all within the prefecture city of Jincheng, also a highly developed coal mining area in the southeast of the Qinshui coal basin. This area also has numerous active mine methane drainage projects underway. Of the seventeen mines selected in the Qinnan gas region fourteen mined the #3 seam, one mined the #3, #9 and #15 seams and two mined the #9 and #15 seams.

Gas Composition

Shouping and Qinnan Gas Regions			
	#3 Seam	#15 Seam	Average
CH4	88.58	89.44	89.01

CO2	3.48	3.00	3.24
N2	7.94	7.56	7.75
C2+	0	0	0
Total	100.00	100.00	100.00

Coal Thickness

Qinnan and Shouping Gas Regions, meters				
	Seam No.	Low	High	Average
Shanxi Fm	1	0	2.28	1.2
	2	0.35	1.95	1
	3	0.2	4.7	1.9
	3-1	0	4.3	1.65
	5	0	3.7	0.65
	6	0	3.85	1.2
Taiyuan Fm	7	0	1.24	0.7
	8	0	4.24	1.8
	9	0	5.73	2.1
	11	0.13	0.9	0.4
	12	0	2.86	1.2
	13	0	1	0.6
	15	5.2	9.5	6.5
	16	0	3.55	0.82
Total		5.88	49.8	21.72

Adsorption Characteristics

Qinnan Gas Region		
Seam No.	V_L m^3/t	P_L MPa
3	44.20	2.31
3	35.30	2.22
3	39.06	2.76
3	47.50	2.78
3	46.39	1.64
3	43.23	1.54
3	35.33	2.13
3	45.64	1.49
3	32.60	2.47
3	40.7	2.40
3	48.15	1.79
Average #3	**41.65**	**2.14**
Std Dev #3	**5.42**	**0.46**

9	43.76	3.57
9	43.05	1.61
Average #9	**43.41**	**2.59**
Std Dev #9	**0.50**	**1.39**
15	51.80	2.19
15	49.60	2.95
15	38.31	2.19
15	35.40	2.39
15	50.40	2.31
Average #15	**45.10**	**2.41**
Std Dev #15	**7.64**	**0.32**
Average All	**42.80**	**2.26**
Std Dev All	**5.79**	**0.54**

7.4 Xishan Coalfield

The Xishan coalfield lies to the northwest of the Qinshui coalfield and includes the Gujiao and Xingjiashe gas regions. Anthracite is the primary coal type produced.

7.5 Xingjiashe Gas Region

The Xingjiashe gas region is in the northern portion of the Xishan coalfield and the mines selected here all lie within the prefecture city of Taiyuan which is also the provincial capital of Shanxi. The Xingjiashe gas region shares adsorption characteristics with the Shouping gas region. Of the four mines selected in the this gas region two mined the #2, one mined the #3 and one mined the #2, #8 and #9 seams.

Gas Composition

Xingjiashe Gas Region				
	#2 Seam	#8 Seam	#9 Seam	Average
CH4	84.11	82.41	79.33	81.95
CO2	5.13	7.96	4.52	5.87
N2	5.76	4.63	11.15	7.18
C2+	5.00	5.00	5.00	5
Total	100.00	100.00	100.00	100.00

Coal Thickness

Xingjiashe Gas Region, meters				
	Seam	Low	High	Average
Shanxi Fm	02	0	2.6	0.81
	03	0	2.6	0.6
	2	0	5.98	2.3

	3u	0	8.99	1.4
	3	0	0.66	1.79
	4	0	4.75	1.38
	4l	0	1.97	0.5
Taiyuan	5	0	2.65	0.57
	6	0	4.33	1.2
	7	0	1.71	0.7
	8	0.4	8	3.9
	9	0	5.26	2.2
	10	0	2.68	0.65
Total		0.4	52.18	18

Adsorption Characteristics

Shouping and Xingjiashe Gas Regions		
Seam No.	V_L m^3/t	P_L MPa
3	31.28	1.85
3	37.16	2.78
3	37.10	2.78
3	24.81	1.93
Average #3	**32.59**	**2.34**
Std Dev #3	**5.09**	**0.45**
15	29.45	1.00
15	32.67	1.98
15	31.54	2.21
15	36.11	2.22
15	41.29	1.25
Average #15	**34.21**	**1.73**
Std Dev #15	**4.14**	**0.51**
Average All	**33.49**	**2.00**
Std Dev All	**4.94**	**0.60**

7.6 Hedong and Huozhou Coalfields

The Hedong and Huozhou coalfields are in southwest Shanxi and produce mostly coking coal. They share the Daning-Jixian gas region

7.7 Daning-Jixian Gas Region

All of the selected mines in the Daning-Jixian gas region lie within the prefecture city of Linfen. Of the twelve mines two mine the #1 and #2 seams, two mine the #2 and #9+10 seams, two mine the #2 and #3 seams, one mines the #2, #3, #9 and #11 seam, one mines the #2, #9+10, and #11 seams, two mine the #2, #3, #7, and #10 seams and two mine the #2 and #9 seams. The mines in this gas region tend to be smaller and in a less developed mining area. These coals also appear to have unusually high ethane content for coal seam gas.

Gas Composition

Daning-Jixian Gas Region					
	#4 Seam	#5 Seam	#8 Seam	#9 Seam	Average
CH4	92.72	92.07	89.99	92.16	91.74
CO2	2.47	2.87	3.13	3.66	3.03
N2	0.03	0.22	0.04	0.10	0.10
C2+	4.78	4.84	6.84	4.08	5.14
Total	100.00	100.00	100.00	100.00	100.00

Coal Thickness

Daning-Jixian Gas Region, meters				
	Seam	Low	High	Average
Shanxi Fm	1	0.1	2.3	0.56
	2	0.1	2.31	0.77
	3	0	2.1	1.36
	4	0.7	6.5	4.5
Taiyuan Fm	5	0	1.6	0.8
	8	0	2.7	1.14
	9	0	5	1.6
	10	0.7	7	3.5
Total		1.6	29.51	14.23

Adsorption Characteristics

Daning-Jixian Gas Region		
Seam No.	V_L m^3/t	P_L MPa
5	19.16	1.63
5	22.94	2.19
5	26.68	2.17
5	22.99	2.01
Average #5	**22.94**	**2.00**
Std Dev #5	**2.66**	**0.22**
8	19.93	2.16
8	16.29	2.12
8	21.04	1.34
8	18.43	1.22
Average #8	**18.92**	**1.71**

Std Dev #8	**1.78**	**0.43**
Average #5 & #8	**20.93**	**1.86**
Std Dev #5 & #8	**3.24**	**0.40**

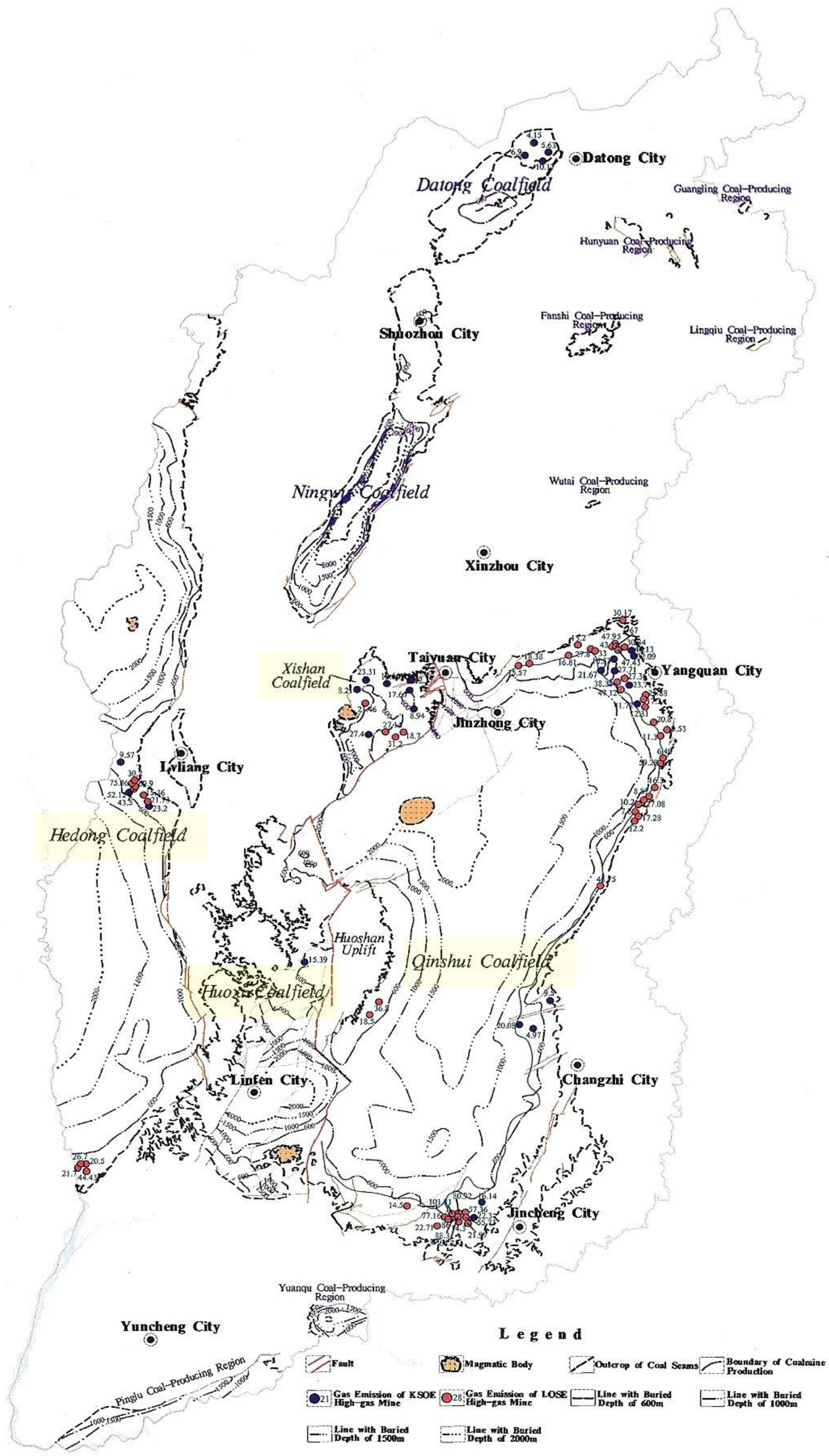


Figure 2: Distribution of High–Gas Coal Mines in Shanxi

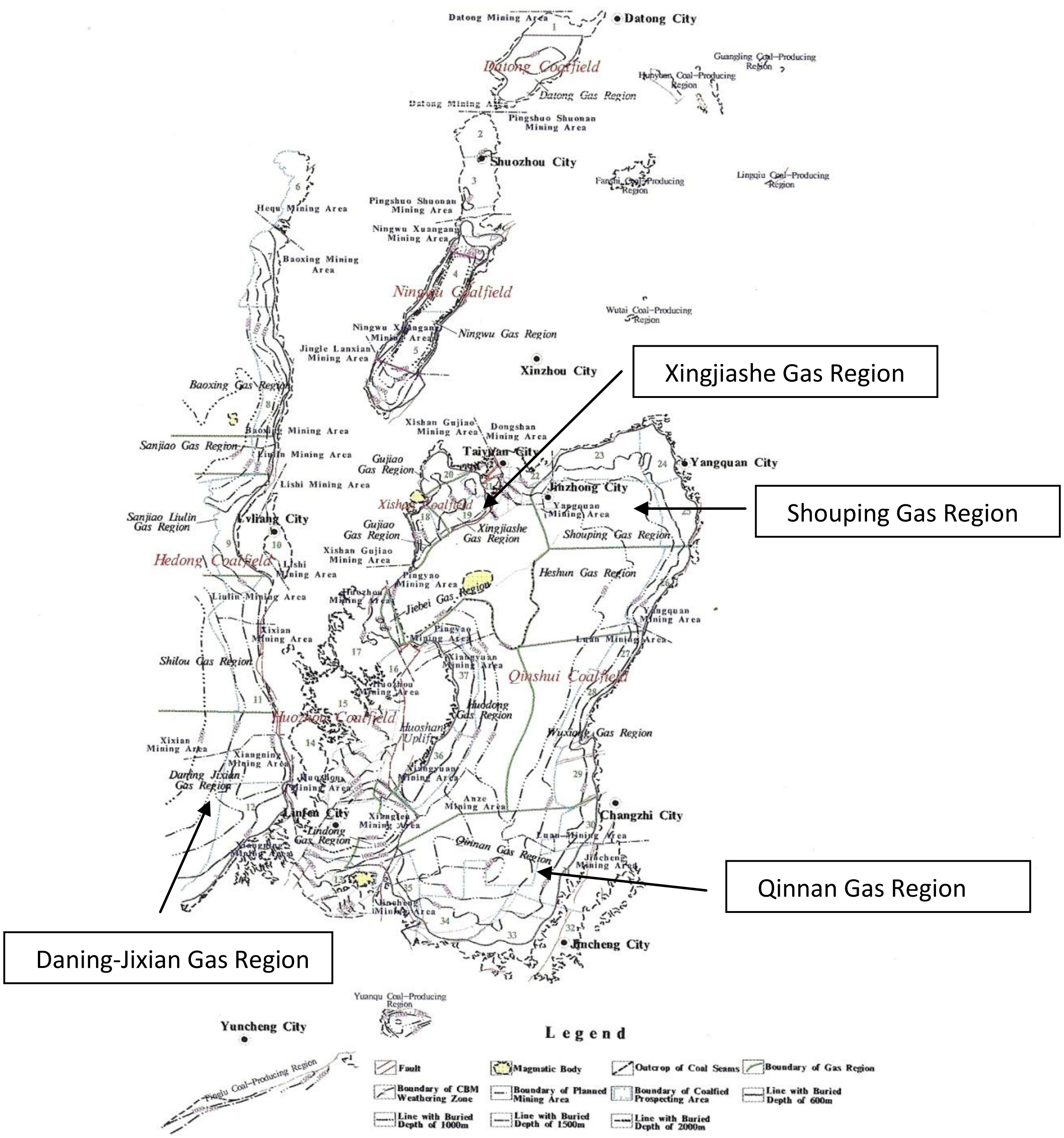


Figure 3: Distribution of Shanxi CBM Accumulation Basins

8. Mine Specific Data

The following tables split out the mine specific data by gas region

Data for mines in the Shouping gas region of the Qinshui coal basin in the prefecture city of Yangquan

Mine Name	Main Shaft Latitude	Main Shaft Longitude	First Year	Last Year	Area, km2	Mined Coal Thickness, m	Coal Produced, Mt	Gas Content, m3/mt
阳泉一矿黄石板平峒 Huangshiban Portal of Yangquan #1 Mine	37°57′56″	113°23′23″	1950	1973	6.21	1.56	7.59	16.3
阳泉一矿北头嘴四尺斜井 Beitouzui Xichi Inclined Mineshaft of Yangquan #1 Mine	37°54′24″	113°29′44″	1957	1988	21.73	1.36	23.1	17.4
阳泉一矿北头嘴七尺平峒 Beitouzui Qichi Mine Portal of Yangquan #1 Mine	37°52′37″	114°24′29″	1905	1988	16.45	2.34	29.7	14.75
阳泉一矿永红矿 Yonghong Mineshaft of Yangquan #1 Mine	37°55′29″	113°30′43″	1951	1976	11.85	1.85	16.5	16.5
阳泉二矿东四尺 Dongsichi Mineshaft of Yangquan #2 Mine	37°51′56″	113°29′7″	1952	1985	20.49	1.36	21.78	17.6
阳泉二矿小南坑 Xiaonankeng Mineshaft of Yangquan #2 Mine	37°51′57″	113°29′7″	1953	1984	22.35	1.31	20.46	16.9
阳泉三矿裕公斜井 Yugong Inclined Mineshaft of Yangquan #3 Mine	37°53′20″	113°28′22″	1958	1980	7.11	2.34	10.89	15.2
阳泉三矿一号平峒井 No.1 Mine Portal of Yangquan #3 Mine	37°52′31″	113°28′58″	1958	1981	21.5	1.37	21.78	17.1
阳泉三矿老丈八井 Old Zhangba Mineshaft of Yangquan #3 Mine	37°52′26″	113°27′32″	1949	1960	2.1	5.31	6.6	7.6
阳泉四矿丈八井一号坑 Zhangbajing No.1 Mineshaft of Yangquan #4 Mine	37°55′16″	113°33′2″	1960	2009	6.4	5.41	26.4	6.9
阳泉四矿丈八井二号坑 Zhangbajing No.2 Mineshaft of Yangquan #4 Mine	37°55′60″	113°31′3″	1963	2009	6.34	5.34	24.42	7.3

Data for mines in the Xingjiashe gas region of the Xishan coal basin in the prefecture city of Taiyuan

Mine Name	Main Shaft Latitude	Main Shaft Longitude	First Year	Last Year	Area, km2	Mined Coal Thickness, m	Coal Produced, Mt	Gas Content, m3/mt
西山煤电白家庄松树坑井 Baijiazhuang Songshu Coal Mine of Xishan Coal Electricity Group	37°57′10″	112°35′24″	1971	2002	5.35	3.6	14.85	9.6
太原煤气化长沟矿 Changgou Coal Mine	37°57′11″	112°35′23″	1998	2009	9.57	3.4	24	9.8
太原市平口矿 Pingkou Coal Mine	37°7′7″	112°17′29″	1956	2009	2.56	6.3	12.01	9.6
太原市桑树洼矿 Sangshuwa Coal Mine	37°39′15″	112°10′55″	1959	2009	4.8	3.41	11.32	9.5

Data for mines in the Qinnan gas region of the Qinshui coal basin in the prefecture city of Jincheng

Mine Name	Main Shaft Latitude	Main Shaft Longitude	First Year	Last Year	Area, km2	Mined Coal Thickness, m	Coal Produced Mt	Gas Content m3/mt
卧庄煤矿 Wozhuang Coal Mine	35°31′10″	112°23′50″	1955	2005	3.78	8.21	21.45	11.68
上孔煤矿义城坑口 Shangkong Yicheng Coal Mine	35°32′41″	112°29′27″	1995	2008	1.3	5.09	3.78	15.3
上孔煤矿上孔坑口 Shangkong Coal Mine	35°30′15″	112°29′44″	1971	2004	1.3	5.05	4.36	11.35
屯城煤矿 Tuncheng Coal Mine	35°31′47″	112°31′37″	1995	2007	1.3	5.14	4.62	11.65
申家庄矿上伏坑口 Shenjiazhuang Shangfu Coal Mine	35°54′60″	112°53′50″	1952	2008	4.95	5.3	18.48	15.2
申家庄矿段家沟坑口 Shenjiazhuang Duanjiagou Coal Mine	35°52′28″	112°56′12″	1952	2006	1.6	5.24	5.35	11.8
万山矿 Wanshan Coal Mine	35°40′32″	112°13′22″	1954	2002	2.38	5.11	7.92	11.9
祥和矿一号井 Xianghe Coal Mine #1 Mineshaft	35°34′44″	111°9′20″	1999	2008	0.8	4.84	1.8	14.1

七岭煤矿 Qiling Coal Mine	35°31′13″	111°22′37″	1998	2008	1.83	2.89	3.36	15.97
天户煤矿 Tianhu Coal Mine	35°32′18″	111°9′57″	1958	1989	4.8	5.16	16.74	11.78
牛山煤矿 Niushan Coal Mine	35°33′2″	111°18′52″	1958	2000	5.1	5.41	18.9	12.1
庄头煤矿 Zhuangtou Coal Mine	35°31′54″	112°20′38″	1956	1999	5.6	5.01	19.35	12.3
云泉煤矿 Yunquan Coal Mine	35°50′14″	112°21′13″	1954	1998	8.6	5.01	29.7	11.9
高良煤矿 Gaoliang Coal Mine	35°52′17″	112°49′53″	1962	1992	3.8	5.22	13.5	11.6
游仙山煤矿 Youxianshan Coal Mine	35°51′46″	113°5′9″	1952	1989	4.9	5.03	16.65	12.4
西沟煤矿 Xigou Coal Mine	35°32′3″	112°22′7″	1970	1993	7.8	2.95	15.53	16.3
伏岩山煤矿 Fuyanshan Coal Mine	35°38′10″	112°17′32″	1962	1986	3.2	5.04	10.8	11.84

Data for mines in the Daning-Jixian gas region of the Huozhou-Hedong coal basin in the prefecture city of Linfen

Mine Name	Main Shaft Latitude	Main Shaft Longitude	First Year	Last Year	Area, km2	Mined Coal Thickness, m	Coal Produced, Mt	Gas Content m3/mt
许村矿许村坑口 Xucun Coal Mine	35°37′47″	111°40′43″	1981	1998	5.9	2.94	11.48	13.33
许村矿老虎吉坑 Xucun Laohuji Coal Mine	35°37′43″	111°40′37″	1981	2000	4.2	2.93	8.55	13.79
水地庄矿 Shuidizhuang Coal Mine	35°58′35″	111°55′41″	1965	2008	2.6	9.31	12.9	14.1
昱洁煤业公司 Yujie Coal Company	35°59′30″	111°56′17″	1956	2009	3.25	9.34	23.85	11.5
古阳矿紫树围井 Guyang Zishuwei Coal Mine	36°25′7″	112°3′33″	1956	2007	5.8	5.1	16.07	8.6
古阳矿安吉井 Guyang Anji Coal Mine	36°25′5″	112°1′33″	1956	2007	5.79	5.14	19.28	9.2
古阳矿二坑口 Guyang Erkeng Coal Mine	36°25′8″	112°2′15″	1956	2007	3.39	9.38	20.35	8.4
南湾煤矿 Nanwan Coal Mine	36°13′43″	111°13′41″	1968	2008	3.31	9.24	17.16	8.1

毛则渠煤矿新口 Maozequ Coal Mine New Shaft	35°47’31”	110°42’5”	1976	2005	2.3	6.11	7.83	7.6
毛则渠煤矿老口 Maozequ Coal Mine Old Shaft	35°49’39”	110°42’48”	1965	2005	1.89	7.64	8.16	8.4
康和洼煤矿 Kanghewa Coal Mine	36°44’29”	111°28’33”	1969	2002	2.35	6.52	9.9	7.5
下岭煤矿 Xialing Coal Mine	36°45’5”	111°28’57”	1970	1998	2.28	6.43	8.4	6.4

Figure 4 shows that the Shouping gas region generally has the highest in-place gas contents followed by Qinnan, Daning-Jixian and Xingjiashe gas regions.

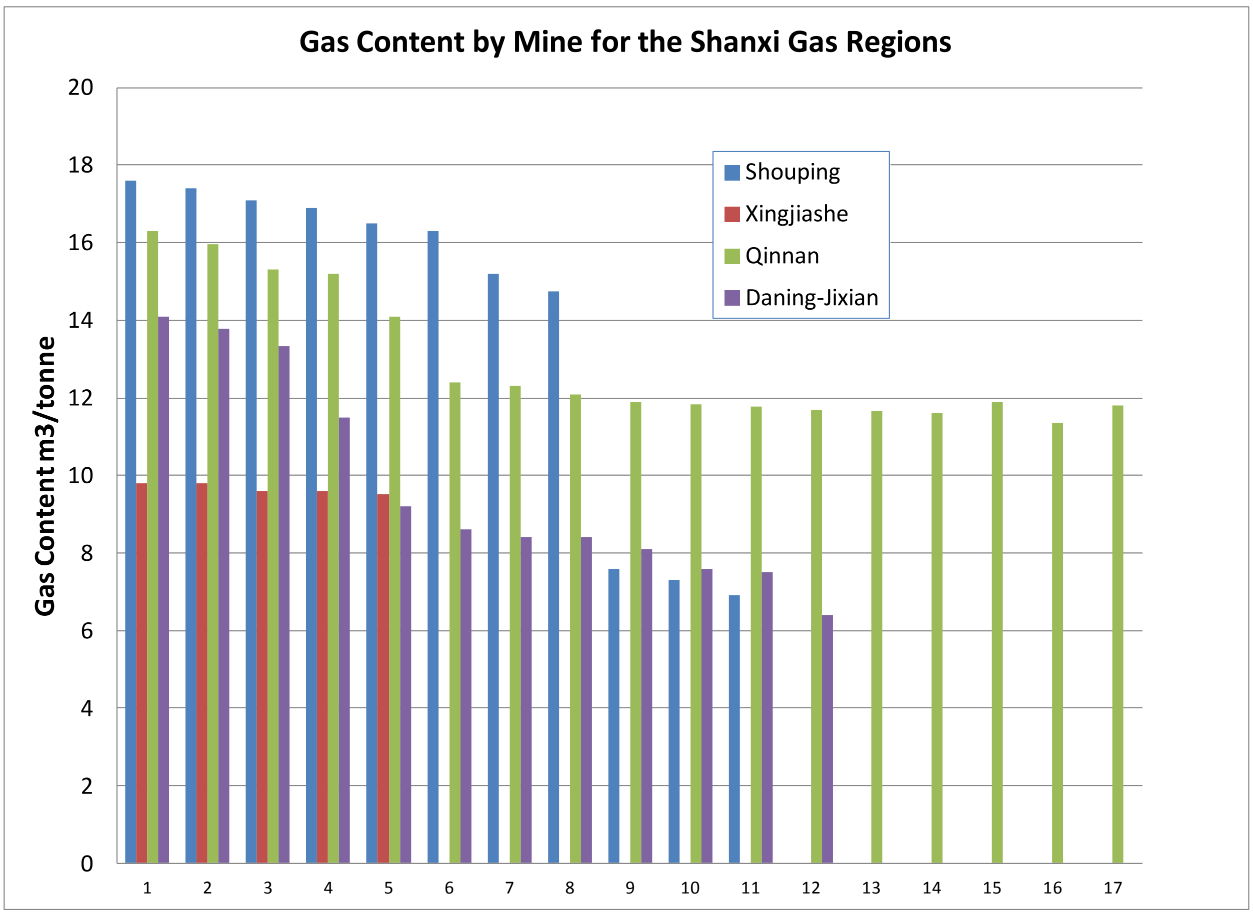


Figure 4: Gas content by mine for the four Shanxi gas regions investigated

9. Results of Analysis

9.1 Calculated Data

The following tables show some of the pertinent results from the material balance calculations. The average coal production rate is simply the mine's total production divided by the number of days from opening to closing. The average specific emissions number, as discussed above, is calculated from the measured gas content of the mined coal plus a function including the log of the ratio of the total coal thickness to the mined coal thickness. The average emission rate is simply the specific emissions multiplied by the average daily mining rate. The year 2012 minus the year of closure is the value of the years since closure. The 20 year recoverable CH_4 is cumulative methane emitted from the closed mine over a twenty year period beginning in 2012 based on the emission rate decay forecast. Both the Initial rate at 2012 and the rate after twenty years is based on the decay function. The nominal generating capacity (NGC) is determined from the heat content of methane being used to generate power at 30% electrical efficiency using the average emission rate over those twenty years. The NGC was chosen as benchmark value because power generation will be the most likely end use option for project development.

Analysis results for mines in the Shouping gas region of the Qinshui coal basin in the prefecture city of Yangquan

Mine Name	Average coal rate, t/d	Average Specific Emissions m^3/t	Average CH_4 Emission Rate m^3/d	Years Since Closure	20 year recoverable CH_4 m^3	Initial Rate m^3/d	Rate after 20 years m^3/d	Nominal Generating Capacity MWe
阳泉一矿黄石板平峒 Huangshiban Portal of Yangquan #1 Mine	904	67.38	60,916	39	162,822,129	25,669	19,170	2.8
阳泉一矿北头嘴四尺斜井 Beitouzui Xichi Inclined Mineshaft of Yangquan #1 Mine	2,042	74.31	151,709	24	629,824,377	98,627	74,751	10.7
阳泉一矿北头嘴七尺平峒 Beitouzui Qichi Mine Portal of Yangquan #1 Mine	980	54.99	53,909	24	279,454,678	41,839	34,757	4.7
阳泉一矿永红矿 Yonghong Mineshaft of Yangquan #1 Mine	1,808	65.39	118,240	36	324,903,025	51,576	37,977	5.5

阳泉二矿东四尺 Dongsichi Mineshaft of Yangquan #2 Mine	1,808	75.17	135,915	27	555,820,011	86,243	66,604	9.4
阳泉二矿小南坑 Xiaonankeng Mineshaft of Yangquan #2 Mine	1,808	72.81	131,654	28	559,725,558	85,995	67,767	9.5
阳泉三矿裕公斜井 Yugong Inclined Mineshaft of Yangquan #3 Mine	1,356	56.67	76,850	32	204,562,437	33,140	23,395	3.5
阳泉三矿一号平峒井 No.1 Mine Portal of Yangquan #3 Mine	2,594	72.90	189,144	31	629,635,568	99,328	74,129	10.6
阳泉三矿老丈八井 Old Zhangba Mineshaft of Yangquan #3 Mine	1,644	22.11	36,338	52	16,741,381	2,854	1,804	0.3
阳泉四矿丈八井一号坑 Zhangbajing No.1 Mineshaft of Yangquan #4 Mine	1,476	19.94	29,435	3	147,659,497	27,245	14,650	2.5
阳泉四矿丈八井二号坑 Zhangbajing No.2 Mineshaft of Yangquan #4 Mine	1,454	21.19	30,822	3	156,620,866	28,613	15,714	2.6

Analysis results for mines in the Xingjiashe gas region of the Xishan coal basin in the prefecture city of Taiyuan

Mine Name	Average coal rate, t/d	Average Specific Emissions m^3/t	Average CH_4 Emission Rate m^3/d	Years Since Closure	20 year recoverable CH_4 m^3	Initial Rate m^3/d	Rate after 20 years m^3/d	Nominal Generating Capacity MWe

西山煤电白家庄松树坑井 Baijiazhuang Songshu Coal Mine of Xishan Coal Electricity Group	1,312	29.85	39,176	10	128,426,915	24,703	12,201	2.2
太原煤气化长沟矿 Changgou Coal Mine	5,978	31.03	185,500	3	489,626,399	140,051	30,961	8.3
太原市平口矿 Pingkou Coal Mine	621	24.48	15,197	3	62,850,231	13,377	5,360	1.1
太原市桑树洼矿 Sangshuwa Coal Mine	620	30.05	18,642	3	102,282,774	17,611	10,944	1.7

Analysis Results for mines in the Qinnan gas region of the Qinshui coal basin in the prefecture city of Jincheng

Mine Name	Average coal rate, t/d	Average Specific Emissions m^3/t	Average CH_4 Emission Rate m^3/d	Years Since Closure	20 year recoverable CH_4 m^3	Initial Rate m^3/d	Rate after 20 years m^3/d	Nominal Generating Capacity MWe
卧庄煤矿 Wozhuang Coal Mine	1,175	28.88	33,948	7	129,358,454	25,105	12,173	2.2
上孔煤矿义城坑口 Shangkong Yicheng Coal Mine	797	45.15	35,967	4	115,185,736	27,186	8,969	1.9
上孔煤矿上孔坑口 Shangkong Coal Mine	362	33.58	12,156	8	49,492,891	9,106	4,935	0.8
屯城煤矿 Tuncheng Coal Mine	1,055	34.26	36,142	5	86,032,479	22,318	5,998	1.5

申家庄矿上伏坑口 Shenjiazhuang Shangfu Coal Mine	904	44.24	39,998	4	207,497,147	36,366	21,830	3.5
申家庄矿段家沟坑口 Shenjiazhuang Duanjiagou Coal Mine	271	34.48	9,359	6	48,793,882	8,218	5,345	0.8
万山矿 Wanshan Coal Mine	452	35.07	15,853	10	72,392,263	12,293	7,860	1.2
祥和矿一号井 Xianghe Coal Mine #1 Mineshaft	548	42.32	23,188	4	73,042,663	17,400	5,633	1.2
七岭煤矿 Qiling Coal Mine	921	56.17	51,704	4	176,349,528	40,088	14,316	3.0
天户煤矿 Tianhu Coal Mine	1,479	34.60	51,191	23	126,114,919	22,004	13,285	2.1
牛山煤矿 Niushan Coal Mine	1,233	34.97	43,112	12	165,135,049	29,141	17,205	2.8
庄头煤矿 Zhuangtou Coal Mine	1,233	36.49	44,990	13	176,002,993	30,461	18,723	3.0
云泉煤矿 Yunquan Coal Mine	1,849	35.30	65,290	14	252,982,944	43,440	27,133	4.3
高良煤矿 Gaoliang Coal Mine	1,233	33.94	41,842	20	107,082,960	19,061	11,042	1.8
游仙山煤矿 Youxianshan Coal Mine	1,233	36.74	45,295	23	129,415,091	22,014	14,015	2.2

西沟煤矿 Xigou Coal Mine	1,850	56.99	105,430	19	330,198,817	56,662	35,521	5.6
伏岩山煤矿 Fuyanshan Coal Mine	1,233	35.06	43,220	26	81,635,309	14,444	8,468	1.4

Analysis results for mines in the Daning-Jixian gas region of the Huozhou-Hedong coal basin in the prefecture city of Linfen

Mine Name	Average coal rate, t/d	Average Specific Emissions m^3/t	Average CH_4 Emission Rate m^3/d	Years Since Closure	20 year recoverable CH_4 m^3	Initial Rate m^3/d	Rate after 20 years m^3/d	Nominal Generating Capacity MWe
许村矿许村坑口 Xucun Coal Mine	1,850	41.02	75,884	14	154,964,915	30,185	14,755	2.6
许村矿老虎吉坑 Xucun Laohuji Coal Mine	1,233	42.48	52,370	12	118,530,130	23,498	11,113	2.0
水地庄矿 Shuidizhuang Coal Mine	822	27.13	22,300	4	78,394,037	17,383	6,620	1.3
昱洁煤业公司 Yujie Coal Company	1,233	22.09	27,237	3	60,905,035	19,188	3,489	1.0
古阳矿紫树围井 Guyang Zishuwei Coal Mine	863	21.72	18,754	5	92,587,265	16,372	9,671	1.6
古阳矿安吉井 Guyang Anji Coal Mine	1,036	23.17	23,996	5	105,724,159	19,990	10,307	1.8
古阳矿二坑口	1,093	16.10	17,602	5	55,268,569	12,571	4,430	0.9

Guyang Erkeng Coal Mine								
南湾煤矿 Nanwan Coal Mine	1,175	15.65	18,391	4	64,503,020	14,484	5,261	1.1
毛则渠煤矿新口 Maozequ Coal Mine New Shaft	740	17.83	13,186	7	43,038,404	8,889	3,820	0.7
毛则渠煤矿老口 Maozequ Coal Mine Old Shaft	559	17.82	9,962	7	33,461,276	6,826	3,010	0.6
康和洼煤矿 Kanghewa Coal Mine	822	17.10	14,058	10	34,446,094	7,230	2,993	0.6
下岭煤矿 Xialing Coal Mine	822	14.68	12,069	14	27,123,182	5,349	2,511	0.5

Figure 5 is a pareto chart of the NGC of each mine by gas region.

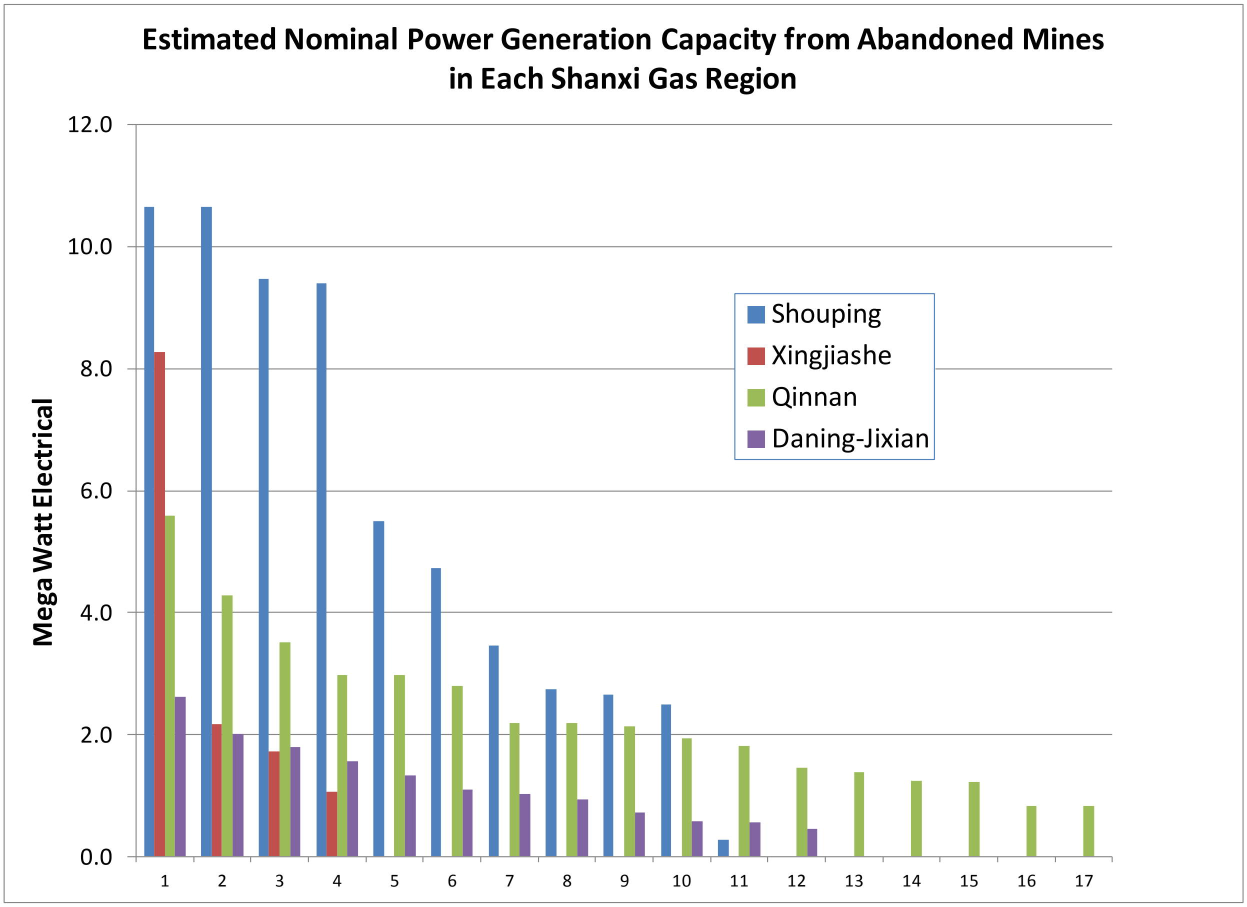


Figure 5: Pareto chart of the estimated NGC for mines within each gas region

This chart shows that the most prospective abandoned mines for development are in the Shouping gas region followed by Qinnan, with Xingjiashe and Daning-Jixian being approximately equal. The Changgou Coal Mine in the Xingjiashe gas region shows a nominal generation capacity of 8.3 MWe, however the data relative to its mine life (11 years to produce 24 million tonnes of coal) and therefore its mining rate and gas productivity is believed to be incorrect.

9.2 Correlation of Data to Highly Prospective Abandoned Mines

Using the NGC as the benchmark against which to compare the prospects of successful AMM development, plots were generated to compare the relative correlation of the NGC to other factors (cumulative methane emissions over a 20 year project life could also be used as a benchmark).

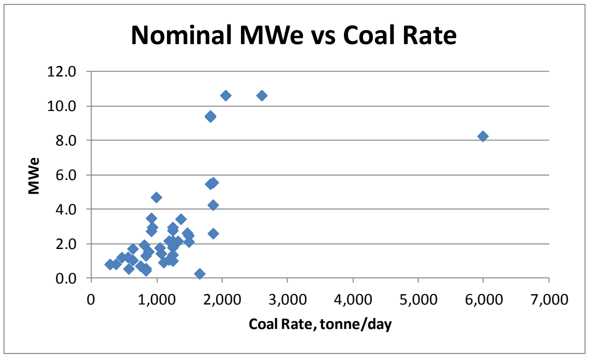


Figure 6: NGC versus average coal rate

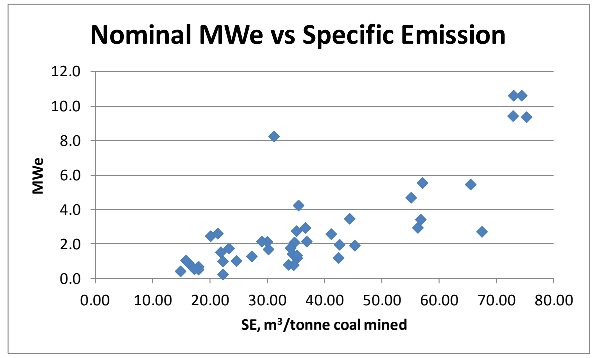


Figure 7: NGC versus specific emissions

Note the outlier at a NGC of 8.3 in each graph. This is the mine noted above as having an anomalously short producing life for the amount of coal produced. The start date for this mine is assumed to be incorrect. The correlation of specific emissions with NGC has the best correlation (R^2 = 0.61). Recall that if a credible value of specific emissions is not available an empirical relationship between the total coal thickness (H_{TC}), the thickness of the mined seam (H_{MS}) and the original gas content can be used to estimate the specific emissions. That was done for this study. The relationship used was

$$SE = GC \times (1.5 + LN(H_{TC} / H_{MS}))$$

So the measured gas content multiplied by $LN(H_{TC} / H_{MS})$ also called the SE factor provides an estimation of the actual specific emissions. This relationship has been tested against abandoned mines in the Illinois basin of the United States that had historical specific emissions values and was found to be in good agreement. This relationship takes into account the diminishing contribution of gas from coal remote from the mined seam. **Figure 7** shows the SE Factor as function of total coal to mined coal thickness ratio.

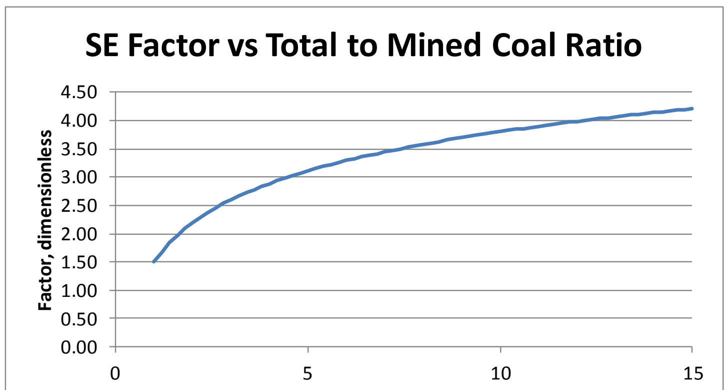


Figure 8

Note the four mines in **Figures 6 and 7** at the high end of the NGC scale. These four mines are within the Shouping gas region. These mines along with having high measured gas content also have the highest SE factors in the data set, all being above 4.25 which means that the mined coal thickness was small compared to the total coal thickness contributing gas to the mine emissions. These mines appeared to have only mined one seam because the total mined thickness ranged from 1.31 meter to 1.37 meter where the total coal package averaged 21.7 meters. Even thought the coal thickness package of the Qinnan and Shouping gas regions were not distinguished from each other, the specific emission factors for the Qinnan gas region were almost all between 2.0 and 3.0. This is because the mined coal thickness was higher, generally between 3 and 8 meters, probably indicating multiple seams being mined. This results in less methane remaining after mining because more coal was extracted as a percentage of the original coal in the system.

Other factors influence the rate and amount of recoverable gas (and therefore NGC) from a particular mine including the length of time since closure. Figures 9 and 10 show two mines; one closed for three years and one closed for 36 years

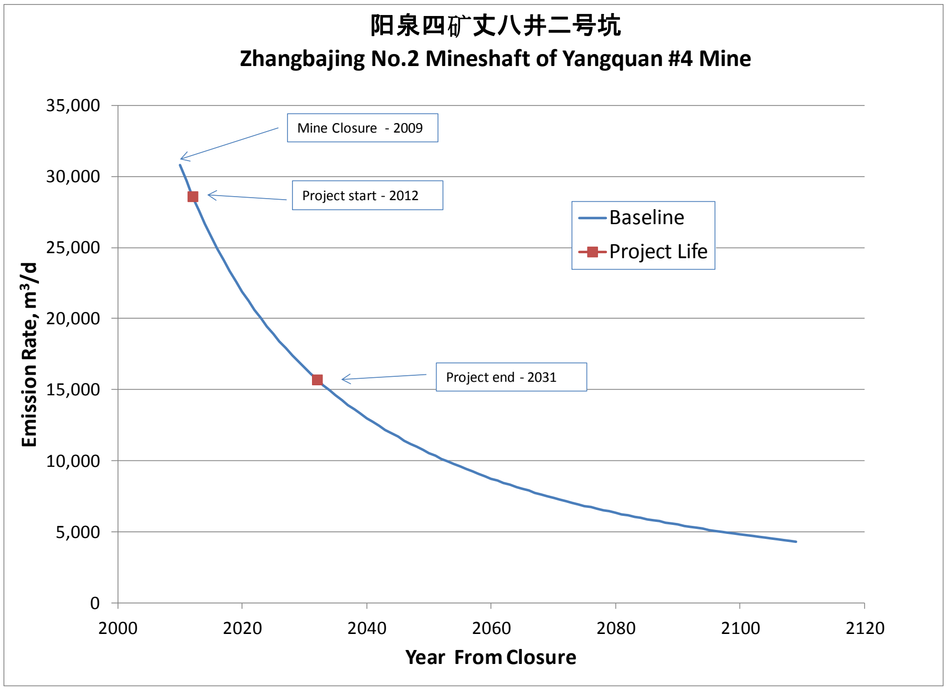


Figure 9: Recently closed mine shows steep decline rate over project life

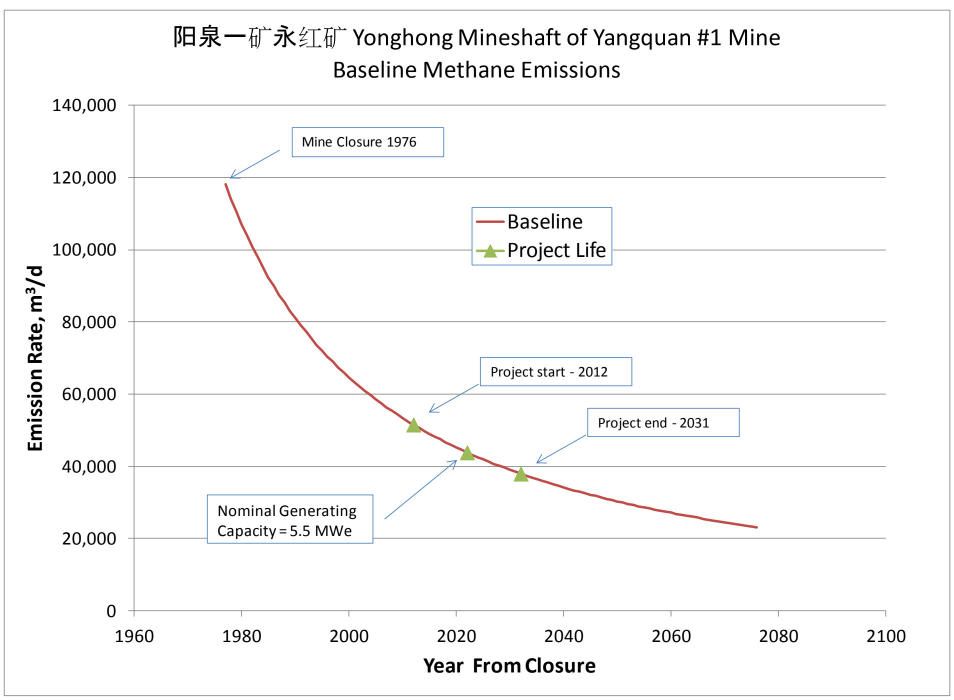


Figure 10: Older mine shows shallow decline rate over project life

9.3 Sensitivity Analysis

The above results and those displayed in the database are based on average values of total coal thickness, methane content and Langmuir pressure and volume by gas region. Because there is a range of data for various coal seams in the different gas regions (as shown in the section on Gas Region Specific Data) it is prudent to test the sensitivity of the analysis results to the range of uncertainty of those parameters. The following tables show the high, mid and low values used for each parameter in order to test the sensitivity of the resulting NGC to this range of variation. Note that the extreme high and low values of the parameter were not used but the values at the 5 and 95 percentile of each distribution.

Shouping	High	Mid	Low
Total Coal Thickness, m	41.89	21.72	11.76
Methane Content	0.97	0.89	0.75
Langmuir Volume, m3/mt	41.62	33.39	25.34
Langmuir Pressure, MPa	2.87	2.00	1.04

Xingjiashe	High	Mid	Low
Total Coal Thickness, m	42.70	18.00	7.10
Methane Content	0.82	0.82	0.82
Langmuir Volume, m3/mt	41.59	33.39	25.34
Langmuir Pressure, MPa	2.86	2.00	1.04

Qinnan	High	Mid	Low
Total Coal Thickness, m	41.89	21.72	11.76
Methane Content	0.97	0.89	0.75
Langmuir Volume, m3/mt	51.85	42.80	32.56
Langmuir Pressure, MPa	3.30	2.26	1.60

Daning-Jixian	High	Mid	Low
Total Coal Thickness, m	24.88	14.23	5.79
Methane Content	0.99	0.92	0.74
Langmuir Volume, m3/mt	27.18	20.93	16.61
Langmuir Pressure, MPa	2.57	1.86	1.24

One coal mine from each gas region was selected to illustrate the results of this analysis which are shown below where the percent high and low are relative to the mid case value.

阳泉一矿永红矿 Yonghong Mineshaft of Yangquan #1 Mine					
Shouping	High	Mid	Low	% High	% Low
Thickness	9	5.5	3	64%	-45%
% CH4	5.7	5.5	4.9	4%	-11%
Isotherm	5.8	5.5	5	5%	-9%

太原市桑树洼矿 Sangshuwa Coal Mine					
Xingjiashe	High	Mid	Low	% High	% Low
Thickness	2.6	1.7	0.8	53%	-53%
% CH4	1.7	1.7	1.7	0%	0%
Isotherm	1.74	1.73	1.71	1%	-1%

牛山煤矿 Niushan Coal Mine					
Qinnan	High	Mid	Low	% High	% Low
Thickness	4.5	2.8	1.4	61%	-50%
% CH4	3.0	2.8	2.4	7%	-14%
Isotherm	2.8	2.8	2.7	0%	-4%

许村矿老虎吉坑 Xucun Laohuji Coal Mine					
Daning-Jixian	High	Mid	Low	% High	% Low
Thickness	3.3	2.0	0.6	65%	-70%
% CH4	2.1	2.0	1.6	5%	-20%
Isotherm	2.2	2.0	1.8	10%	-10%

This analysis shows that the sensitivity to total coal thickness is very large. When investigating a particular mine for a potential AMM project it is very important to determine as closely as possible the total coal thickness within the area of influence. This parameter affects the original coal in-place, the original gas in-place, the SE factor, the SE, and the coal and methane remaining after mining.

9.4 Model Validation

Following the construction of this baseline emission model it was tested on some abandoned mines in the Illinois basin of the United States. Some of these mines have been producing AMM since 2003. Comparing the model prediction with the actual methane production should help to determine the validity of this approach.

The following graphs **in Figure 11** show how the predicted emissions relate to the measure methane produced from eight of these mines. Most of these mines had a slight positive pressure within the void when drainage wells penetrated the workings. The free gas in the void can be produced at very high rates which are why the first year rates of some of the mines are well above the baseline emission rate.

The model does not take into account the free gas in the void; only the adsorbed gas in the remaining coal and therefore under-predicts the actual initial production as well as the cumulative gas production

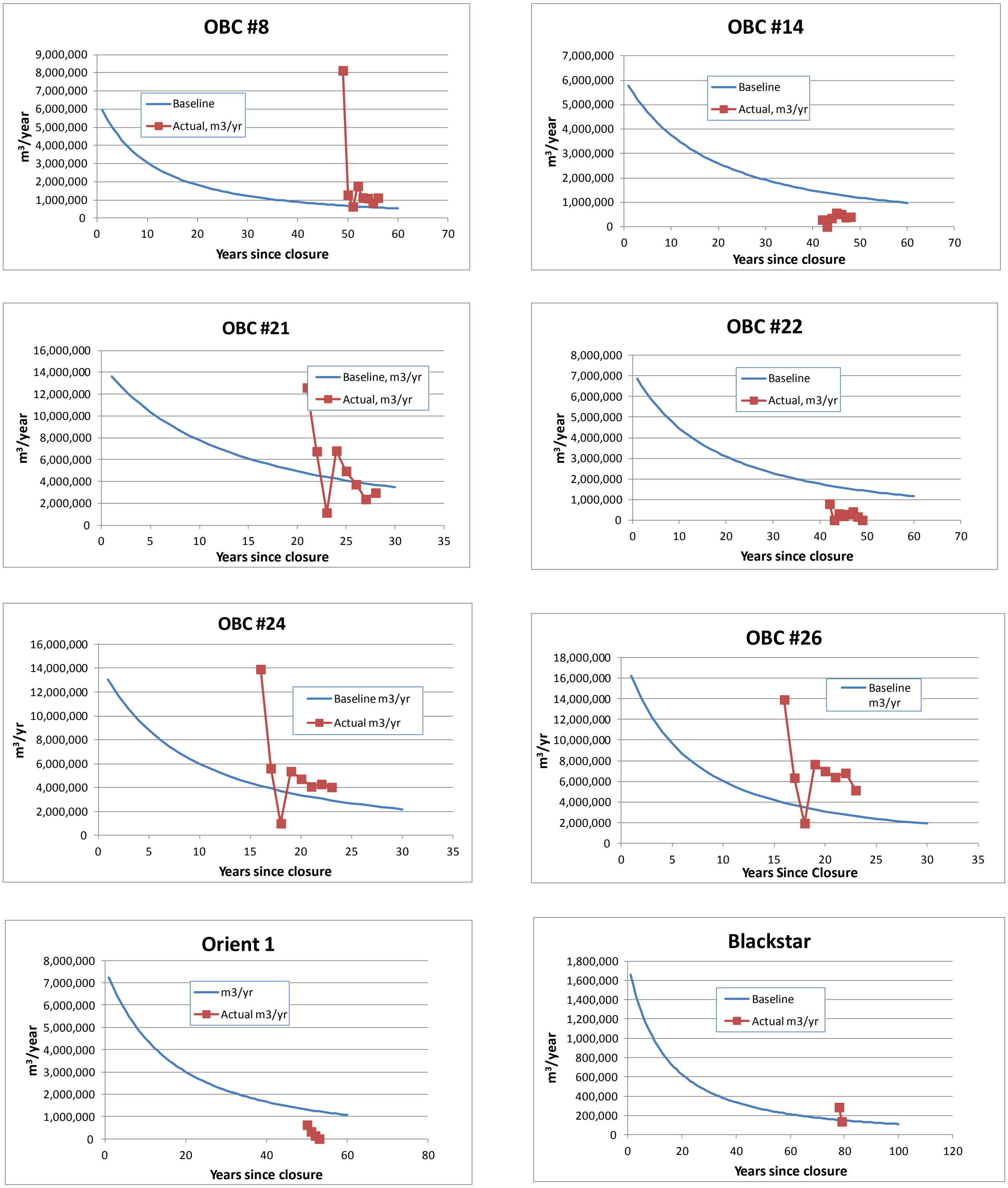


Figure 11: Predicted baseline methane emissions and actual production data from eight abandoned coal mines in the Illinois basin of the United States

The older mines such as OBC 8, 14, 22 and Orient 1 and Blackstar were room and pillar mines. The newer mines such as OBC 21, 24, and 26 were longwall mines. The extensive fracturing above and below the mined seam in the longwall mines ensured that the entire coal section was contributing gas to the mine whereas this may not be the case for the room and pillar mines. This multiple mine project produced for about a year then was suspended after the initial high rates related to gas under pressure in the void was depleted. A new operator restarted the project about a year later. After this point it appears that production appears to follow the baseline emission rate fairly well and is, at least for the newer mines and more recently closed mines, somewhat conservative.

10. Case Studies

The following three case studies are presented to demonstrate how the information obtained in the study can be used to select a potential AMM development candidate. These studies used the interactive GIS database (www.chinamethane.org) together with the mine data analysis to select potential development sites. The "Coal Mine Methane Project Cash Flow Model" was then used to perform a pro forma analysis of the economic viability of a project.

The three projects are centered on three abandoned mine shafts:

1. Xigou Coal Mine in the Qinnan gas region of the city of Jincheng in the Qinshui coal basin
2. No. 1 Mine Portal of Yangquan #3 Mine in the Shouping gas region of the city of Yangquan in the Qinshui coal basin
3. Xucun Coal Mine in the Daning-Jixian gas region of the city of Linfen in the Huozhou coal basin

These three mines were selected based on a variety of potential project sizes, the presence of nearby population centers, and the presence of other potential projects sites nearby. The following three tables from the online database list the input and analysis results for the three mines.

Mine Name	Xigou Coal Mine
City	Jincheng
Basin	Qinshui
Gas Region	Qinnan
Main Shaft Latitude	35.53
Main Shaft Longitude	112.37
Total Coal Thickness in Region m	21.72
Year of initial Production	1970
Year of closure	1993
Mining Area km2	7.8
Mined Coal Thickness m	2.95
Coal Produced Mt	15.53
Gas Content m3mt	16.3
Average Daily Mining Rate mtd	1849.91
Average Emission Rate m3d	105429.7
Coal Remaining mt	213181600
Percent Methane in coal	0.89
Yrs Since Closure	19
CH4 20 Year recoverable m3	330198816.84
Initial Rate m3d	56661.8

Rate after 20 years m3d	35521.41
Nominal Mwe	5.59

Mine Name	No.1 Mine Portal of Yangquan #3 Mine
City	Yangquan
Basin	Qinshui
Gas Region	Shouping
Main Shaft Latitude	37.88
Main Shaft Longitude	113.48
Total Coal Thickness in Region m	21.72
Year of initial Production	1958
Year of closure	1981
Mining Area km2	21.5
Mined Coal Thickness m	1.37
Coal Produced Mt	21.78
Gas Content m3mt	17.1
Average Daily Mining Rate mtd	2594.4
Average Emission Rate m3d	189143.61
Coal Remaining mt	608643000
Percent Methane in coal	0.89
Yrs Since Closure	31
CH4 20 Year recoverable m3	629635568.07
Initial Rate m3d	99327.95
Rate after 20 years m3d	74129.11
Nominal Mwe	10.65

Mine Name	Xucun Coal Mine
City	Linfen
Basin	Huozhou
Gas Region	Daning-Jixian
Main Shaft Latitude	35.63
Main Shaft Longitude	111.68
Total Coal Thickness in Region m	14.23

Year of initial Production	1981
Year of closure	1998
Mining Area km2	5.9
Mined Coal Thickness m	2.94
Coal Produced Mt	11.48
Gas Content m3mt	13.33
Average Daily Mining Rate t/d	1850.12
Average Emission Rate m3/d	75883.91
Coal Remaining mt	101861950
Percent Methane in coal	0.92
Yrs Since Closure	14
CH4 20 Year recoverable m3	154964915.13
Initial Rate m3d	30185.12
Rate after 20 years m3d	14755.31
Nominal Mwe	2.62

The following table compares the most important parameters for determining the predicted methane recovery for each mine

	Xigou	Yangquan #3	Xucun
Total Coal Thickness, m	21.72	21.72	14.23
Mined Area, km2	7.8	21.5	5.9
Years Since Closure	19	31	14
Gas Content, m3/t	16.3	17.1	13.33
SE Factor	3.5	4.26	3.08
Coal Remaining, Mt	213	609	102
Gas Remaining, Bm3	1.920	6.509	0.686
20 Year Recoverable Gas, Bm3	0.330	0.630	0.155

The Yangquan #3 mines has the largest quantities in all of the categories and although being abandoned for a longer time still is expected to have significantly more recoverable gas than the other two mines.

The following satellite photos show the locations of these mines relative to other abandoned mines, roads and towns.


Satellite
Xigou
Zhuangtou
Wozhuang
Google
500 m
2000 ft
Imagery ©2012 Cnes/Spot Image, DigitalGlobe, GeoEye - Terms of Use


Yonghong shaft Yangquan #1
Satellite
Beitouzui Xichi shaft Yangquan #1
Yugong shaft Yangquan #3
Old Zhangba shaft Yangquan #3
No. 1 Portal Yangquan #3
Dongsichi shaft Yangquan #2
Google
1 km
1 mi
GeoEye - Terms of Use

Road maps can also be displayed showing town and road names and railroads.

As is shown in the middle photo, the No. 1 Mine Portal of Yangquan #3 Mine is in an area of numerous other closed mines and nearby roads, railroads and poputlation centers. It also happens to be in an area of active coal mining activity which includes active mine methane capture and utilization.

10.1 Pro Forma Economics

Two end use scenarios were run for each mine; one with power generation and one with gas sales. Electricity and natural gas prices were obtained from the CMOP publication "China's Energy Markets: Anhui, Chongqing, Henan, and Guizhou Provinces". Table 15 was used for Shanxi coal fired wholesale power price. The subsidy for CMM power generation was added to this. The tables below shows the best estimate price of the power or gas sold at these sites. Table 31 was used for the natural gas price for sales to the West to East pipeline that runs through Shanxi Province.

CMM Power Sales Price		
	RMB/kWhr	$/kWhr
Wholesale	0.235	0.037
Subsidy	0.25	0.040
Total	0.485	0.077

Gas Sale Price			
Gas Price	RMB/m3	RMB/mmbtu	$/mmbtu
Wholesale	1.20	34.0	5.39
Subsidy	0.20	5.7	0.90
Total	1.40	39.6	6.28

In order to determine the capital and operating cost of project development whether for power generation or gas sales, the number and spacing of wells necessary to drain the mine at its estimated average rate over the 20 year life of the project must be determined. Based on RCE's experience with AMM projects, wells drilled into abandoned mines are generally in pressure communication with each other. This means that one well should be able to drain the entire mine. However every well drilled into an abandoned mine will have a different productivity. That is, the production rate will vary even if the static bottom-hole pressure is the same for each well. This is caused by the pressure loss due to the tortuous path that the gas must travel in order to reach the wellbore. This tortuous path is related to roof collapse, roadway seals that impede but don't totally impede flow and partial flooding of areas of the mine. Therefore multiple wells need to be drilled to achieve the full drainage potential of the mine.

In order to determine the expected number of wells needed to drain a mine, the average rate of production per well needs to be estimated and this needs to be related to the estimated maximum production from the mine. RCE's experience with AMM wells suggests that an average per well rate of 400 Mcf/d (~11,000 m^3/d) total gas is reasonable. Therefore if a mine is expected to drain an average of 2,300 Mcf/d of 70% methane gas, six wells will need to be drilled (rounding up). These wells will need to be drilled in strategic locations based on mine maps developed at the closure of the mines so that areas most connected to large drainage areas are targeted.

For economic analysis purposes these wells are assumed to be spaced equidistance apart based on the area of the mine. Therefore if six wells are to be drilled on a 2,000 acre (7.8 km^2) mine then each will be expected to drain 320 acres (1.3 km2) and the distance between the wells will be 3,740 feet (1140 m). This value will be used to calculate the cost of laying pipe between the wells. The number of wells and depth to the mine will also be in the cost calculation. Therefore the number of wells and distance between the wells will be dependent on the expected rate of recovery and the area of the mine.

10.2 Data Input and Results

The input data and analysis results from the cash flow model are found in Appendix A. The tables below summarize this by mine and for the power generation scenario.

Data input that is common among all mines for power generation	
Gathering & Delivery System	
Cost of satellite compressors	1000 $/HP
Distance from the drainage area to the onsite project	1000 ft
Cost of installing header pipe from the drainage area	40 $/ft
Compressor and blower efficiencies	0.035 HP/mcfd
Drainage Well & Blower Development Costs	

Cost of well-head blowers	1000 $/HP
Mine depth	1000 ft
Drilling cost	140 $/ft
Gas Availability	
Percent Methane in Drainage Gas	70 %
Fraction of CMM available after losses	95 %
User-Defined Inputs	
Planned project operational lifetime	20 years
Developer's equity share in the project	100 %
Carbon credit unit sale price	2 $/tonne CO2E
Percent of CMM is consumed by prime-mover	10 %
Sales price of CMM-based electricity	0.077 $/kWh
Capital cost of treatment, engine-gen set, & electrical eqp	1.3 $000/kW
O&M cost of the reciprocating engine	0.02 $/kWh
The overall efficiency of the engine-generator set	35 % (LHV)
Default Parameters:	
Inflation rate	2.5 %
Real discount rate	12 %
Royalty, severance tax, and negotiation fees	20 %
Contingency factor	5 %
Annual escalation rate for carbon credits	2 %
Hours per year will the engine operate	7500 hrs/year

Mine specific input values			
	Xigou	Yangquan	Xucun
Number of drainage wells are being utilized	6	11	3
The spacing between drainage wells, ft	3740	2762	4600
CMM drained per day (methane), Mcf/d	1600	3050	750

Pro forma economic analysis results from CMOP cash flow model			
	Xigou	Yangquan	Xucun
Total capital cost $	$11,082,000	$20,381,000	$5,418,000
Total annual cost $/year	$793,000	$1,513,000	$372,000
Carbon credits earned per year tonne/year	165,984	316,407	79,068
Internal rate of return (IRR)	25.43%	26.33%	24.41%
Net present value $	$10,256,000	$20,214,000	$4,608,000
Installed Electrical Capacity MW	5.29	10.08	2.48

The input data and analysis results from the cash flow model are found in Appendix A. The tables below summarize this by mine and for the gas sales scenario. The first data table above that shows the common parameters for the power generation scenario are the same for the gas sales scenario except for the capital and expense rows. Those parameters common to all mines but unique to the gas sales scenario are in the following table. The mine specific values (number of wells, spacing and production rate are the same for the gas sales scenarios.

Data input that is common among all mines for gas sales	
Distance to the natural gas pipeline	5000 ft
Cost of electric power used by the project	77 $/MWh
Price of the methane sold to the pipeline	6.28 $/mmBtu(HHV)
Installed cost of high pressure line from project to natural gas pipeline	40 $/ft

Pro forma economic analysis results from CMOP cash flow model			
	Xigou	Yangquan	Xucun
Total capital cost $	$7,856,000	$11,583,000	$5,481,000
Total annual cost $/year	$1,115,000	$1,854,000	$682,000
Carbon credits earned per year tonne/year	165,984	316,407	79,068
Internal rate of return (IRR)	22.08%	30.76%	10.94%
Net present value $	$5,335,000	$15,320,000	-$,349,000
Quantity of exported methane Mcf/year	373,864	712,678	175,249

The pro forma economic analysis shows that gas sales bring about a better return than power generation only for the largest of the projects, No. 1 Mine Portal Yangquan #3. This is because the capital cost is for each mine in the gas sales case is fairly independent of the flow rate (for example the high pressure pipeline to the sales line). This is also the reason for the relatively poor results for the two smaller projects. It should be noted that the gas sale case includes removal of nitrogen and carbon dioxide by pressure swing adsorption down to 4% and also includes high pressure compression (900 psig). In the case of gas sales in China, it might be at low pressure with no nitrogen removal necessary because AMM gas is generally relatively high quality (>50%) and will be adequate for use as town gas or boiler fuel.

The similar rates of return associated with the power generation projects is related to the capital and operation costs being directly related to the volume of gas produced. Good rates of return in the mid 20% are shown for these projects based on the best estimate of the power sale price and the carbon price. It takes a zero price for carbon and 0.055 $/kWhr to bring the power generation cases down to a zero rate of return.

The wholesale price of 0.235 RMB/kWhr (0.37 $/kWhr) is not enough to provide a positive rate of return so the subsidy is clearly necessary. It is also clear that at least 6,000,000 m^3/year (212,000 Mcf/year) of methane is needed for a gas sales project to be successful.

Qualifying emission reductions from AMM projects has been done under a methodology accepted under the Verified Carbon Standard but no methodology has yet been adopted under the Clean Development Mechanism.

10.3 Recommendations

The largest of the potential sites, the No. 1 Mine Portal of Yangquan #3 Mine appears to be the most attractive for further evaluation as it had the best rate of return under both end use scenarios. It also appears from the GIS mapping near population centers, road and rail transportation, other potential AMM sites and is also near some large active mine power generation centers. Its potentially large size will also provide economies of scale not captured in the pro forma analysis.

A recommended program going forward for a project at the No. 1 Mine Portal of Yangquan #3 Mine includes:

- Contacting the Yangquan Coal Mining Group who was the operator when active to determine if they maintain ownership rights to workings and gas held within
- Establish that CMM incentives for active mines also applies to abandoned mine methane recovery
- Establish a working relationship with the mine owner, local officials, grid power provider and other stakeholders
- Obtain more mine specific detailed information including mine maps, stratigraphic sections, information on past emissions, possible flooding and shaft and in-mine sealing procedures in order to test the assumptions used in this initial analysis
- Test a vent pipe or drill a well to determine the in-mine gas pressure and gas composition
- Perform a short (~1 week) open flow test at the vent pipe or drill hole to ensure sufficient mine volume is in communication with the wellbore. Monitor rate, pressure and composition throughout test.
- Install a flare or a packaged power generation set of approximately 1 MW for extended constant rate flow test and monitor gas composition and bottom-hole pressure through time
- Investigate other possible wellbore locations based on the mine maps
- Investigate other abandoned mine sites in the area

A phased approach to these types of projects is important in order to avoid over-building project facilities based on high initial rates that may be associated with pressure buildup in the mine void which does not reflect the long term gas deliverability from the adsorbed gas in the remaining coal.

11. Results and Conclusions

This study was designed to help redress the lack of knowledge of, and focus on, abandoned mines by producing a systematic inventory of abandoned mine methane emissions in China, with an initial focus on the coal bearing regions of Shanxi Province. The following was developed during the course of this study

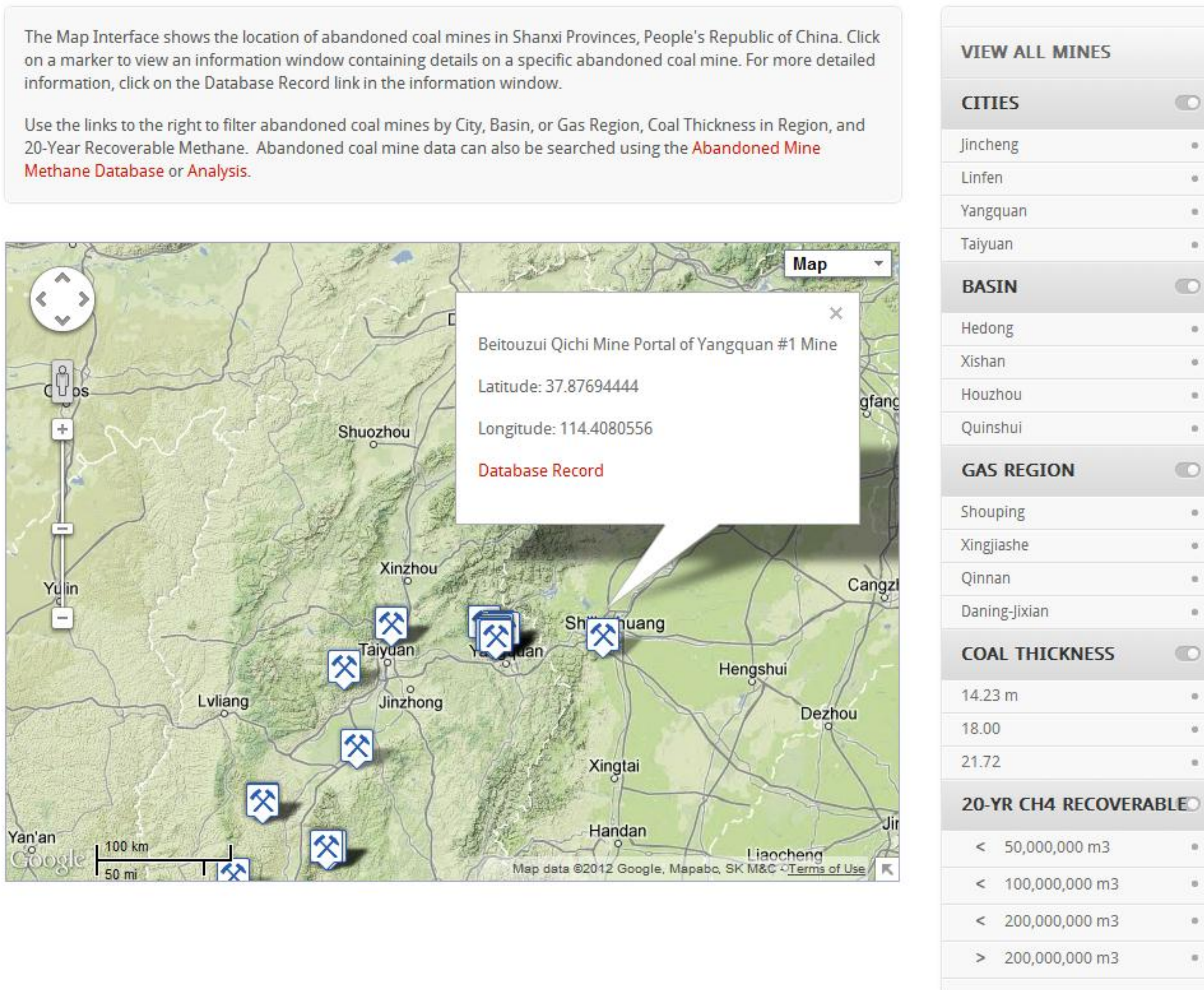
- A comprehensive set of government documents, both national and provincial, were accumulated and summarized regarding policies on the closure and consolidation of coal mines in China as well as policies regarding the incentives available to the coal mining industry for the capture and utilization of CMM.

- Coal characteristics relevant to methane content and production were cataloged for the various gas regions of the Qinshui coal basin.
- Specific information about the size, location, coal production, gas contents and opening and closure dates for forty-four (44) abandoned mines in the Qinshui coal basin was gathered in cooperation with the Shanxi Fenwei Energy Consulting Co. Ltd.
- An approach was developed to estimate the AMM resource available for use and the probable rate of recovery of that resource based on a combination of gas material balance, methane emission rate during mining and a decline function based on an adsorption isotherm for the relevant gas region. This methodology can be used to identify abandoned mines that may be candidates for methane capture and use projects in any coal basin by providing estimates of the remaining resource and possible methane production rates.
- The Shanxi case study found that of the 44 abandoned mines studied 36 are expected to be able to produce over 60 million m3 over a twenty year project life. The largest of these mines may produce as much as 630 million m3.
- Of the 44 mines analyzed three from different gas regions were selected for pro-forma economic analysis case studies. These studies showed that power generation projects could be economically instituted given that the current government power price incentives are obtained. It was also found that only the largest of projects would be economically viable as gas treatment and high pressure pipeline sales projects.
- An online platform was created to present the above data and analysis. The online platform, which is available at www.chinamethane.org, has three primary tools to facilitate interaction with and analysis of project data: (1) a geographic information system that presents the abandoned mine data using Google Maps API v3; (2) a relational MySQL database that enables users to interact with the abandoned mine dataset using the GIS interface, the custom charting system, or a separate search interface; and (3) a charting system that presents aggregate and mine-specific data using dynamic HTML5 charts with data pulled from the MySQL database. In addition to these tools, the platform contains reports and analysis generated throughout the project. The system uses the extensible Joomla framework for content management and administrative control. This framework allows different levels of users—e.g., administrators, registered users, etc.—to easily interact with the underlying dataset and database. It also provides an efficient and flexible backbone for tying the GIS system, MySQL database, and custom charting tool together into a unified framework.

Abandoned Mine Geographic Information System

The GIS tool allows users to visually interact with the abandoned mine data using Google Maps API v3. Abandoned mines are indicated by interactive markers on the map. Selecting a marker triggers an information window containing the name of the mind, its longitude and latitude, and a hyperlink to its record within the MySQL database. The GIS tool has several predefined views that users can use to filter the abandoned mine data (**Image 1**). Users can, for instance, choose to view only mines associated with a specific city—i.e., Jincheng, Linfen, Yangquan, or Taiyun; those associated with a specific basin—i.e., Hedong, Xishan, Houzhou, or Quinshui; those associated with a given gas region—i.e., Shouping, Xingjiashe, Qinnan, Daning-Jixian; those associated with a specific coal thickness—i.e., 14.23 meters, 18 meters, or 21.72 meters; or those associated with a specific 20-year methane recoverability rate—e.g., less than 50 million m^3 or greater than 200 million m^3.

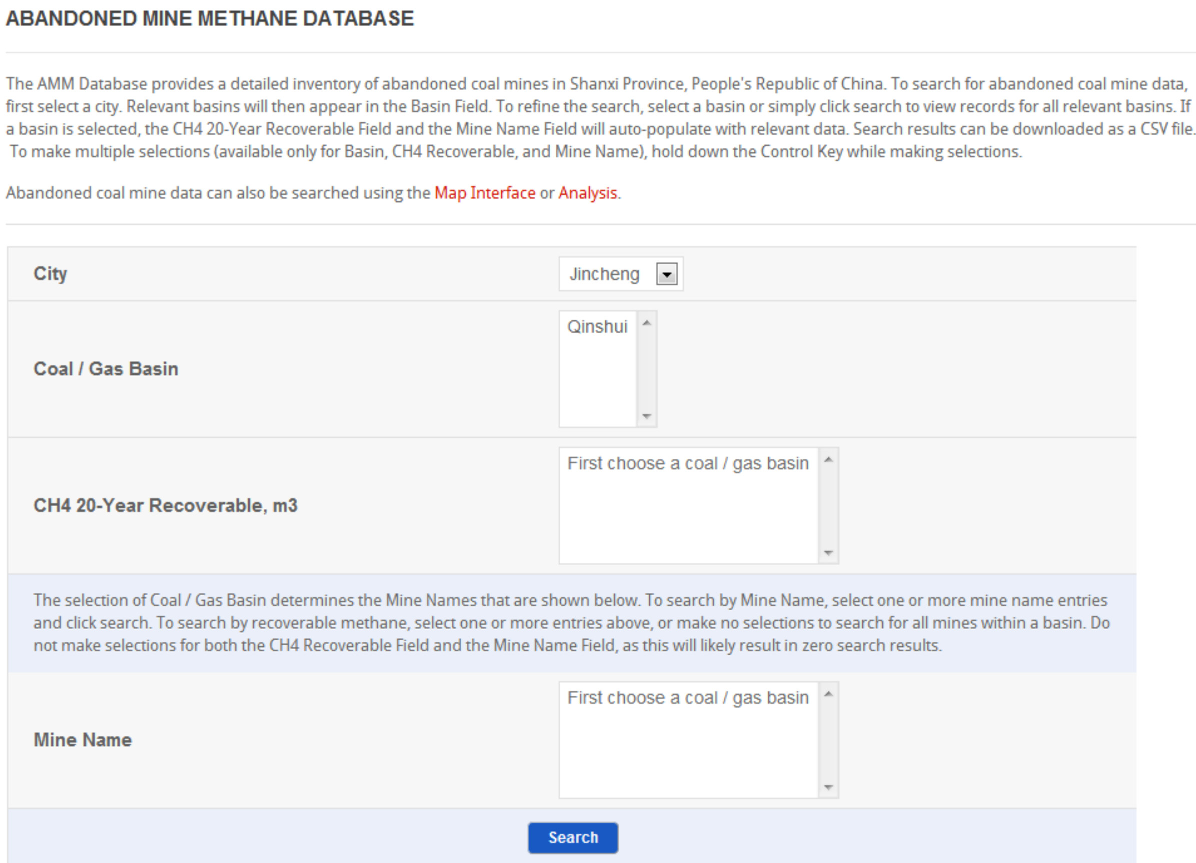
Image 1: Screenshot of GIS Map Interface



Abandoned Mine Methane Database

Project data is stored in the Abandoned Mine Methane Database—a MySQL database that utilizes the Joomla framework as a front-end for user interaction. Users can search for abandoned coal mine data based on city, coal or gas basin, 20-year methane recoverability rate, or by mine name (**Image 2**).

Image 2: Screenshot of the Abandoned Mine Methane Database Search Interface



After the search parameters are selected, the database returns a list of mines that meet the search criteria. This list page provides the users with a quick overview of the relevant mines, including: mine name, city, basin, gas region, year of initial production, year of closure, 20 year methane recoverability rate, and methane remaining after 20 years (**Image 3**). The data contained in this overview can also be downloaded as a CSV file. The MySQL database automatically generates this file and includes only the mines that meet the selected search criteria.

Image 3: Screenshot of Sample List Page for the AMM Database

Search Again | Download Data

Mine Name	City	Basin	Gas Region	Year of initial Production	Year of closure	CH4 20 Year recoverable m3	Rate after 20 years m3d	
Wozhuang Coal Mine	Jincheng	Qinshui	Qinnan	1955	2005	129358454.46	12172.94	Details
Shangkong Yicheng Coal Mine	Jincheng	Qinshui	Qinnan	1995	2008	115185735.62	8968.77	Details
Shangkong Coal Mine	Jincheng	Qinshui	Qinnan	1971	2004	49492891.12	4935.08	Details
Tuncheng Coal Mine	Jincheng	Qinshui	Qinnan	1995	2007	86032478.6	5997.82	Details
Shenjiazhuang Duanjiagou Coal Mine	Jincheng	Qinshui	Qinnan	1952	2006	48793882.15	5345.25	Details
Wanshan Coal Mine	Jincheng	Qinshui	Qinnan	1954	2002	72392262.88	7860.08	Details
Xianghe Coal Mine #1 Mineshaft	Jincheng	Qinshui	Qinnan	1999	2008	73042663.01	5633.22	Details
Qiling Coal Mine	Jincheng	Qinshui	Qinnan	1998	2008	176349528.48	14316.37	Details
Tianhu Coal Mine	Jincheng	Qinshui	Qinnan	1958	1989	126114919.35	13284.74	Details
Niushan Coal Mine	Jincheng	Qinshui	Qinnan	1958	2000	165135048.86	17205.17	Details
Zhuangtou Coal Mine	Jincheng	Qinshui	Qinnan	1956	1999	176002992.79	18723.16	Details
Yunquan Coal Mine	Jincheng	Qinshui	Qinnan	1954	1998	252982944.39	27133.27	Details
Gaoliang Coal Mine	Jincheng	Qinshui	Qinnan	1962	1992	107082959.69	11041.51	Details
Youxianshan Coal Mine	Jincheng	Qinshui	Qinnan	1952	1989	129415091.24	14014.63	Details
Xigou Coal Mine	Jincheng	Qinshui	Qinnan	1970	1993	330198816.84	35521.41	Details
Fuyanshan Coal Mine	Jincheng	Qinshui	Qinnan	1962	1986	81635309.01	8467.86	Details

Records 1-16 of 16

Users can then select a mine to view its full record. The full record contains 22 information fields (**Image 4**). The underlying MySQL database contains additional records for each of the abandoned mines; however, only these 21 fields are available through the Joomla frontend.

Image 4: Screenshot of AMM Database Records Page for a Specific Mine

Search Again

Mine Name	Wozhuang Coal Mine
City	Jincheng
Basin	Qinshui
Gas Region	Qinnan
Main Shaft Latitude	35.52
Main Shaft Longitude	112.4
Total Coal Thickness in Region m	21.72
Year of initial Production	1955
Year of closure	2005
Mining Area km2	3.78
Mined Coal Thickness m	8.21
Coal Produced Mt	21.45
Gas Content m3mt	11.68
Average Daily Rate mtd	1175.34
Average Emission Rate m3d	33947.7
Coal Remaining mt	89387160
Percent Methane in coal	0.89
Yrs Since Closure	7
CH4 20 Year recoverable m3	129358454.46
Intial Rate m3d	25104.96
Rate after 20 years m3d	12172.94
Nominal Mwe	2.19

Back

Record 1 of 16

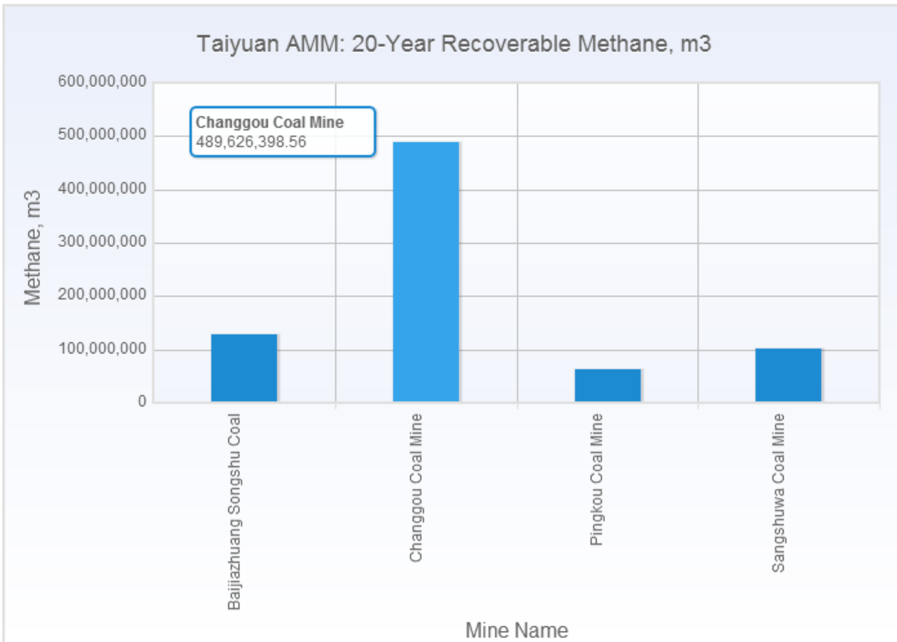
AMM Charting / Analysis System

The AMM charting system uses HTML5 to generate charts derived from database records in the MySQL database.

Similar to the GIS tool, data for groups of mines or specific mines is visually rendered using dynamically generated bar and pie charts; and the underlying data is made available as a CSV file for users to download (**Image 5**). Links are auto-generated to the database records, allowing uses to easily navigate from the charting application to the database record.

Image 5: Screenshot of the AMM Charting Application

TAIYUAN ANALYSIS: CH4 20-YEAR RECOVERABLE



Download Data

Mine Name	CH4 20 Year recoverable m3	
Baijiazhuang Songshu Coal Mine of Xishan Coal Electricity Group	128,426,914.88	Details
Changgou Coal Mine	489,626,398.56	Details
Pingkou Coal Mine	62,850,230.57	Details
Sangshuwa Coal Mine	102,282,774.20	Details

ANALYSIS HOME
JINCHENG ANALYSIS
LINFEN ANALYSIS
TAIYUAN ANALYSIS
CH4 20-Year Recoverable
CH4 Initial Release Rate and Rate After 20 Years
YANGQUAN ANALYSIS

In addition to providing a systematic, supported and transparent resource to facilitate the identification and development of abandoned mine methane projects, the study is intended to improve knowledge of abandoned mine methane emissions and methodologies to forecast these emissions, provide a template for similar work, and enable Chinese and other national authorities to better estimate methane emissions.

This sample set of forty-four abandoned coal mines (out of thousands in Shanxi province) may be emitting over 500,000,000 m^3 per year of methane or about 7,000,000 tCO2e based on this analysis. And although these represent the larger of the recently abandoned mines this large figure should warrant more aggressive investigation to assess and both mitigate as well as to utilize this greenhouse gas as clean energy fuel.

Appendix A

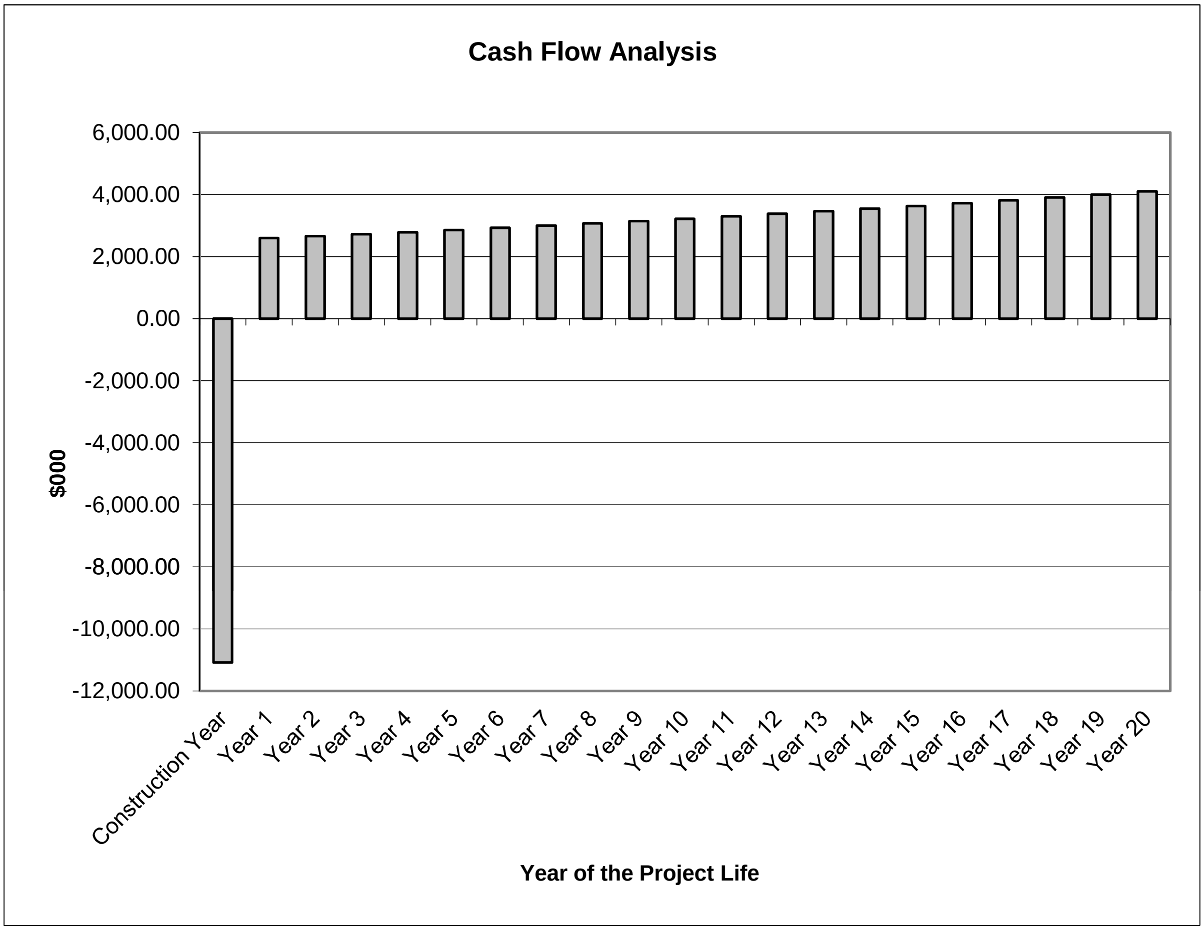
The following pages were extracted from the U.S. EPA Coalbed Methane Outreach Program's Coal Mine Methane Project Cash Flow Model and present the input data and analysis results for the mines used as case studies in the GMI Report "Methane Emissions from Abandoned Coal Mines in China". The results for both power generation and gas sales are presented for each mine.

Coalbed Methane Scenario: Xigou Power Generation

Gathering & Delivery System	
What is the cost of satellite compressors?	1000 $/HP
What is the distance from the drainage area to the onsite project?	1000 ft
What is the cost of installing header pipe from the drainage area?	40 $/ft
What are the compressor and blower efficiencies?	0.035 HP/mcfd
How many drainage wells are being utilized?	6
What is the spacing between drainage wells?	3740 ft
Drainage Well & Blower Development Costs	
What is the cost of well-head blowers?	1000 $/HP
What is the mine depth?	1000 ft
What is the drilling cost?	140 $/ft
What is the fraction of this project's drainage system cost that will be included in the analysis?	100 %
Gas Availability	
What is the source of the coal mine methane?	abandoned mine gas drainage
Percent Methane in Drainage Gas	70 %
What do you expect the CMM drained per day to be?	1600 mcf/d
What is the fraction of CMM available after losses?	95 %
User-Defined Inputs	
What is the planned project operational lifetime?	20 years
What is the loan term?	5 years
What interest rate is charged for the loan?	6 %
What is the developer's equity share in the project?	100 %
What is the carbon credit unit sale price?	2 $/tonne CO2E
What percent of CMM is consumed by prime-mover use?	10 %
For what price can CMM-based electricity be sold?	0.077 $/kWh
Capital cost of treatment, engine-gen set, & electrical eqp?	1.3 $000/kW
What is the O&M cost of the reciprocating engine?	0.02 $/kWh
What is the overall efficiency of the engine-generator set?	35 % (LHV)
Default Parameters:	
What is the inflation rate?	2.5 %
What is the real discount rate?	12 %
What are the royalty, severance tax, and negotiation fees?	20 %
What is the contingency factor?	5 %
What is the annual escalation rate for carbon credits?	2 %
How many hours per year will the engine operate?	7500 hrs/year

Estimated Outputs:

Available CMM for Other Projects	0	mcf/d
Total capital cost	11,082,000	$
Total annual cost	793,000	$/year
Equity amount	11,082,000	$
Loan amount	0,000	$
Carbon credits earned per year	165,984	tonne/year
Internal rate of return (IRR)	25.43	%
Net present value	10,256,000	$
Installed Electrical Capacity	5.29	MW



Coalbed Methane Scenario: Xigou Gas Sales

Gathering & Delivery System

What is the cost of satellite compressors?	1000 $/HP
What is the distance from the drainage area to the onsite project?	1000 ft
What is the cost of installing header pipe from the drainage area?	40 $/ft
What are the compressor and blower efficiencies?	0.035 HP/mcfd
How many drainage wells are being utilized?	6
What is the spacing between drainage wells?	3740 ft

Drainage Well & Blower Development Costs

What is the cost of well-head blowers?	1000 $/HP
What is the mine depth?	1000 ft
What is the drilling cost?	140 $/ft
What is the fraction of this project's drainage system cost that will be included in the analysis?	100 %

Gas Availability

What is the source of the coal mine methane?	abandoned mine gas drainage
Percent Methane in Drainage Gas	70 %
What do you expect the CMM drained per day to be?	1600 mcf/d
What is the fraction of CMM available after losses?	95 %

User-Defined Inputs

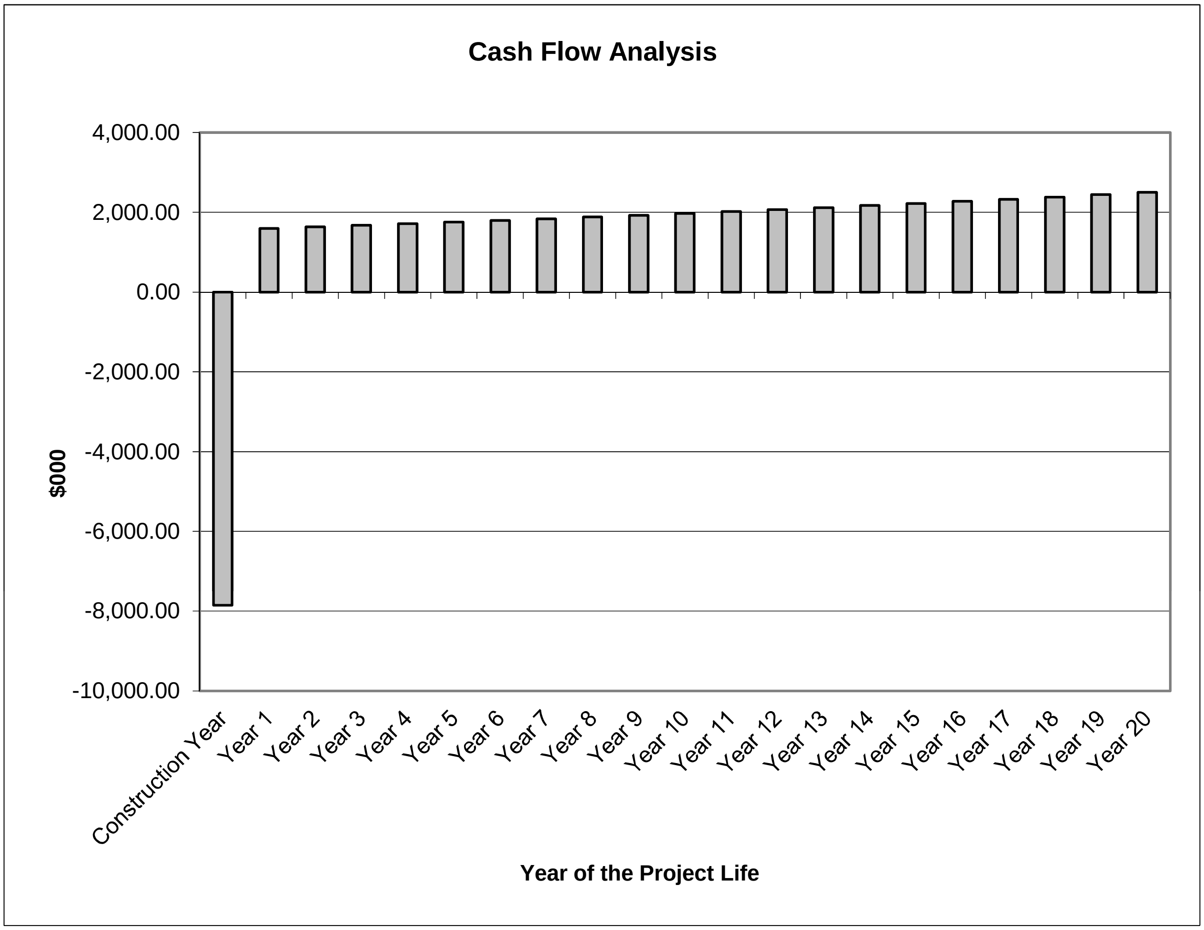
What is the planned project operational lifetime?	20 years
What is the loan term?	5 years
What interest rate is charged for the loan?	6 %
What is the developer's equity share in the project?	100 %
What is the carbon credit unit sale price?	2 $/tonne CO2E
What percent of CMM is consumed by prime-mover use?	10 %
What is the distance to the natural gas pipeline?	5000 ft
What is the cost of electric power used by the project?	77 $/MWh
What is the price of the methane sold to the pipeline?	6.28 $/mmBtu(HHV)
What is the installed cost of high pressure line from project to natural ga	40 $/ft

Default Parameters:

What is the inflation rate?	2.5 %
What is the real discount rate?	12 %
What are the royalty, severance tax, and negotiation fees?	20 %
What is the contingency factor?	5 %
What is the annual escalation rate for carbon credits?	2 %
How many hours per year will the project operate?	7500 hrs/year

Estimated Outputs:

Available CMM for Other Projects	0	mcf/d
Total capital cost	7,856,000	$
Total annual cost	1,115,000	$/year
Equity amount	7,856,000	$
Loan amount	0,000	$
Carbon credits earned per year	168,679	tonne/year
Internal rate of return (IRR)	22.08	%
Net present value	5,335,000	$
Quantity of exported Methane	373,864	Mcf/year



Coalbed Methane Scenario: Yangquan #3 Power Generation

Gathering & Delivery System

What is the cost of satellite compressors?	1000	$/HP
What is the distance from the drainage area to the onsite project?	1000	ft
What is the cost of installing header pipe from the drainage area?	40	$/ft
What are the compressor and blower efficiencies?	0.035	HP/mcfd
How many drainage wells are being utilized?	11	
What is the spacing between drainage wells?	2762	ft

Drainage Well & Blower Development Costs

What is the cost of well-head blowers?	1000	$/HP
What is the mine depth?	1000	ft
What is the drilling cost?	140	$/ft
What is the fraction of this project's drainage system cost that will be included in the analysis?	100	%

Gas Availability

What is the source of the coal mine methane?	abandoned mine gas drainage	
Percent Methane in Drainage Gas	70	%
What do you expect the CMM drained per day to be?	3050	mcf/d
What is the fraction of CMM available after losses?	95	%

User-Defined Inputs

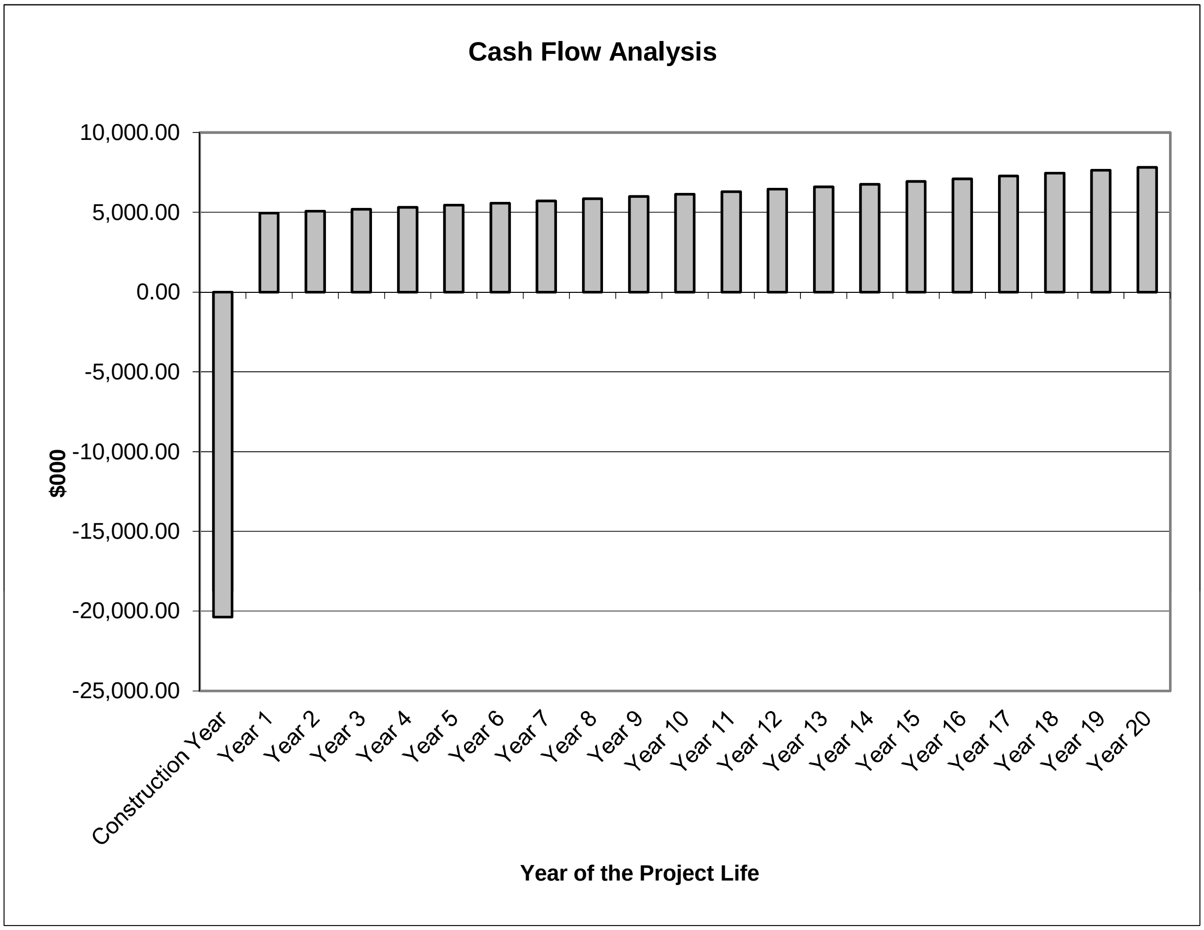
What is the planned project operational lifetime?	20	years
What is the loan term?	5	years
What interest rate is charged for the loan?	6	%
What is the developer's equity share in the project?	100	%
What is the carbon credit unit sale price?	2	$/tonne CO2E
What percent of CMM is consumed by prime-mover use?	10	%
For what price can CMM-based electricity be sold?	0.077	$/kWh
Capital cost of treatment, engine-gen set, & electrical eqp?	1.3	$000/kW
What is the O&M cost of the reciprocating engine?	0.02	$/kWh
What is the overall efficiency of the engine-generator set?	35	% (LHV)

Default Parameters:

What is the inflation rate?	2.5	%
What is the real discount rate?	12	%
What are the royalty, severance tax, and negotiation fees?	20	%
What is the contingency factor?	5	%
What is the annual escalation rate for carbon credits?	2	%
How many hours per year will the engine operate?	7500	hrs/year

Estimated Outputs:

Available CMM for Other Projects	0	mcf/d
Total capital cost	20,381,000	$
Total annual cost	1,513,000	$/year
Equity amount	20,381,000	$
Loan amount	0,000	$
Carbon credits earned per year	316,407	tonne/year
Internal rate of return (IRR)	26.33	%
Net present value	20,214,000	$
Installed Electrical Capacity	10.08	MW



Coalbed Methane Scenario: Yangquan #3 Gas Sales

Gathering & Delivery System

What is the cost of satellite compressors?	1000	$/HP
What is the distance from the drainage area to the onsite project?	1000	ft
What is the cost of installing header pipe from the drainage area?	40	$/ft
What are the compressor and blower efficiencies?	0.035	HP/mcfd
How many drainage wells are being utilized?	11	
What is the spacing between drainage wells?	2762	ft

Drainage Well & Blower Development Costs

What is the cost of well-head blowers?	1000	$/HP
What is the mine depth?	1000	ft
What is the drilling cost?	140	$/ft
What is the fraction of this project's drainage system cost that will be included in the analysis?	100	%

Gas Availability

What is the source of the coal mine methane?	abandoned mine gas drainage	
Percent Methane in Drainage Gas	70	%
What do you expect the CMM drained per day to be?	3050	mcf/d
What is the fraction of CMM available after losses?	95	%

User-Defined Inputs

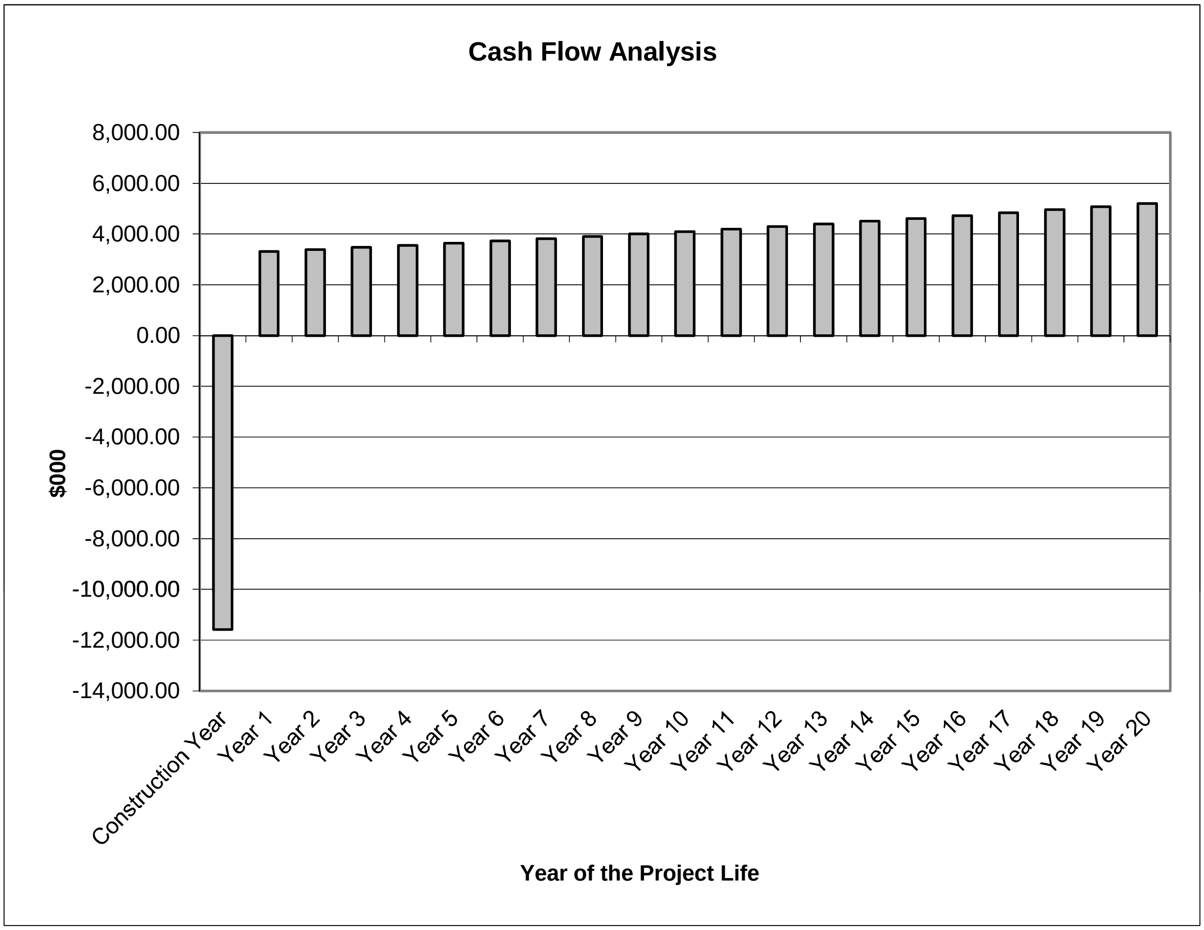
What is the planned project operational lifetime?	20	years
What is the loan term?	5	years
What interest rate is charged for the loan?	6	%
What is the developer's equity share in the project?	100	%
What is the carbon credit unit sale price?	2	$/tonne CO2E
What percent of CMM is consumed by prime-mover use?	10	%
What is the distance to the natural gas pipeline?	5000	ft
What is the cost of electric power used by the project?	77	$/MWh
What is the price of the methane sold to the pipeline?	6.28	$/mmBtu(HHV)
What is the installed cost of high pressure line from project to natural gi	40	$/ft

Default Parameters:

What is the inflation rate?	2.5	%
What is the real discount rate?	12	%
What are the royalty, severance tax, and negotiation fees?	20	%
What is the contingency factor?	5	%
What is the annual escalation rate for carbon credits?	2	%
How many hours per year will the project operate?	7500	hrs/year

Estimated Outputs:

Available CMM for Other Projects	0	mcf/d
Total capital cost	11,583,000	$
Total annual cost	1,854,000	$/year
Equity amount	11,583,000	$
Loan amount	0,000	$
Carbon credits earned per year	321,545	tonne/year
Internal rate of return (IRR)	30.76	%
Net present value	15,320,000	$
Quantity of exported Methane	712,678	Mcf/year



Coalbed Methane Scenario: Xucun Power Generation

Gathering & Delivery System

What is the cost of satellite compressors?	1000	$/HP
What is the distance from the drainage area to the onsite project?	1000	ft
What is the cost of installing header pipe from the drainage area?	40	$/ft
What are the compressor and blower efficiencies?	0.035	HP/mcfd
How many drainage wells are being utilized?	3	
What is the spacing between drainage wells?	4600	ft

Drainage Well & Blower Development Costs

What is the cost of well-head blowers?	1000	$/HP
What is the mine depth?	1000	ft
What is the drilling cost?	140	$/ft
What is the fraction of this project's drainage system cost that will be included in the analysis?	100	%

Gas Availability

What is the source of the coal mine methane?	abandoned mine gas drainage	
Percent Methane in Drainage Gas	70	%
What do you expect the CMM drained per day to be?	750	mcf/d
What is the fraction of CMM available after losses?	95	%

User-Defined Inputs

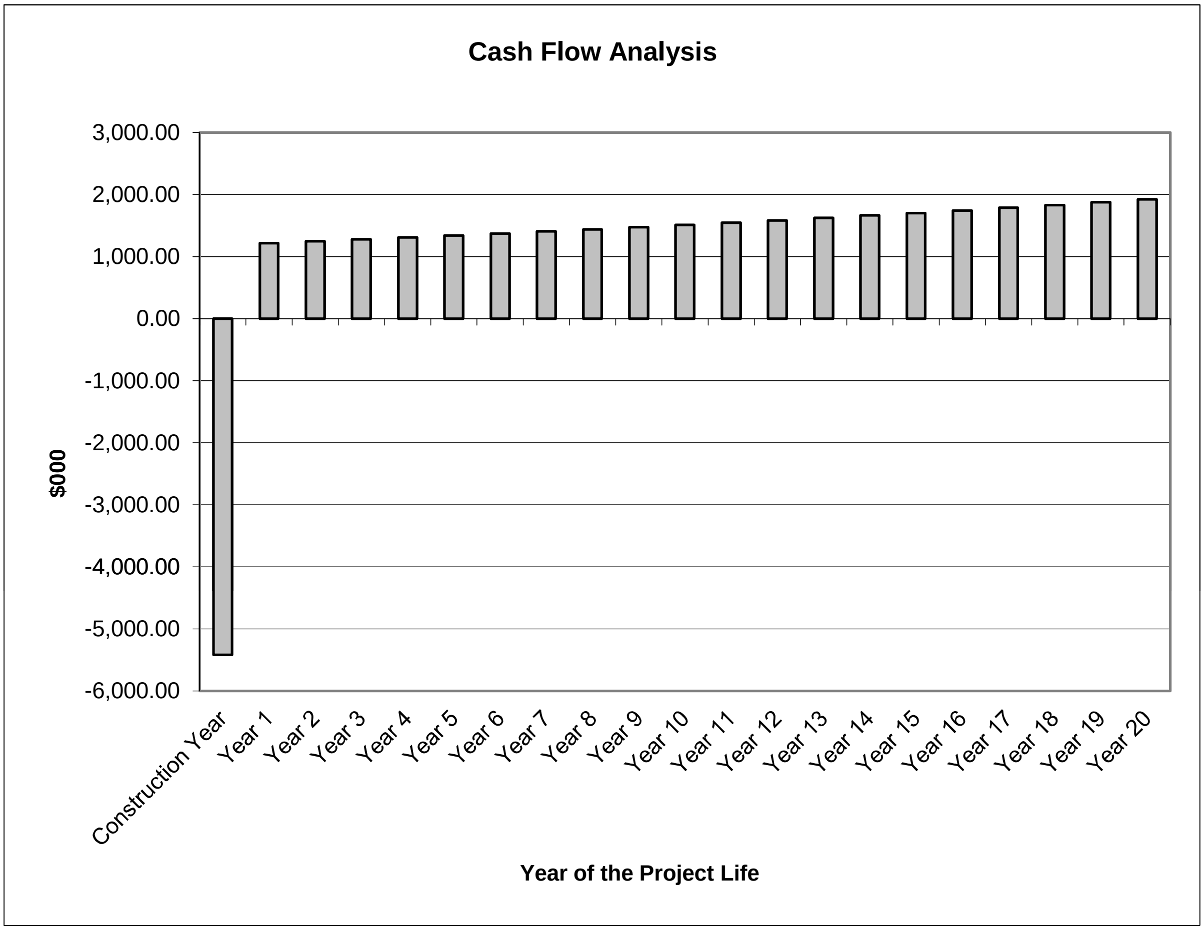
What is the planned project operational lifetime?	20	years
What is the loan term?	5	years
What interest rate is charged for the loan?	6	%
What is the developer's equity share in the project?	100	%
What is the carbon credit unit sale price?	2	$/tonne CO2E
What percent of CMM is consumed by prime-mover use?	10	%
For what price can CMM-based electricity be sold?	0.077	$/kWh
Capital cost of treatment, engine-gen set, & electrical eqp?	1.3	$000/kW
What is the O&M cost of the reciprocating engine?	0.02	$/kWh
What is the overall efficiency of the engine-generator set?	35	% (LHV)

Default Parameters:

What is the inflation rate?	2.5	%
What is the real discount rate?	12	%
What are the royalty, severance tax, and negotiation fees?	20	%
What is the contingency factor?	5	%
What is the annual escalation rate for carbon credits?	2	%
How many hours per year will the engine operate?	7500	hrs/year

Estimated Outputs:

Available CMM for Other Projects	0	mcf/d
Total capital cost	5,418,000	$
Total annual cost	372,000	$/year
Equity amount	5,418,000	$
Loan amount	0,000	$
Carbon credits earned per year	77,805	tonne/year
Internal rate of return (IRR)	24.41	%
Net present value	4,608,000	$
Installed Electrical Capacity	2.48	MW



Coalbed Methane Scenario: Xucun Gas Sales

Gathering & Delivery System

What is the cost of satellite compressors?	1000	$/HP
What is the distance from the drainage area to the onsite project?	1000	ft
What is the cost of installing header pipe from the drainage area?	40	$/ft
What are the compressor and blower efficiencies?	0.035	HP/mcfd
How many drainage wells are being utilized?	3	
What is the spacing between drainage wells?	4600	ft

Drainage Well & Blower Development Costs

What is the cost of well-head blowers?	1000	$/HP
What is the mine depth?	1000	ft
What is the drilling cost?	140	$/ft
What is the fraction of this project's drainage system cost that will be included in the analysis?	100	%

Gas Availability

What is the source of the coal mine methane?	abandoned mine gas drainage	
Percent Methane in Drainage Gas	70	%
What do you expect the CMM drained per day to be?	750	mcf/d
What is the fraction of CMM available after losses?	95	%

User-Defined Inputs

What is the planned project operational lifetime?	20	years
What is the loan term?	5	years
What interest rate is charged for the loan?	6	%
What is the developer's equity share in the project?	100	%
What is the carbon credit unit sale price?	2	$/tonne CO2E
What percent of CMM is consumed by prime-mover use?	10	%
What is the distance to the natural gas pipeline?	5000	ft
What is the cost of electric power used by the project?	77	$/MWh
What is the price of the methane sold to the pipeline?	6.28	$/mmBtu(HHV)
What is the installed cost of high pressure line from project to natural ga	40	$/ft

Default Parameters:

What is the inflation rate?	2.5	%
What is the real discount rate?	12	%
What are the royalty, severance tax, and negotiation fees?	20	%
What is the contingency factor?	5	%
What is the annual escalation rate for carbon credits?	2	%
How many hours per year will the project operate?	7500	hrs/year

Estimated Outputs:

Available CMM for Other Projects	0	mcf/d
Total capital cost	5,481,000	$
Total annual cost	682,000	$/year
Equity amount	5,481,000	$
Loan amount	0,000	$
Carbon credits earned per year	79,068	tonne/year
Internal rate of return (IRR)	10.94	%
Net present value	-349,000	$
Quantity of exported Methane	175,249	Mcf/year