U.S. EPA
Coalbed Methane
OUTREACH PROGRAM

Feasibility Study for Coal Mine Methane Drainage and Utilization

Inner Mongolia Tai Xi Group Coal Mines, Innner Mongolia, China

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Acronyms and Abbreviations

BM	build margin
CAPEX	capital expenditure
CBM	coalbed methane
CBP	closed borehole pressure
CDM	clean development mechanism
CER	Certified Emission Reduction
CH_4	methane
CHP	combined heat and power
CMM	coal mine methane
CMOP	Coalbed Methane Outreach Program
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
EB	emissions balancing
EPA	Environmental Protection Agency
ERG	Eastern Research Group, Inc.
g/cm^3	gram per cubic centimeter
Genset	generator set
GHG	greenhouse gas
GMI	Global Methane Initiative
IC	Internal combustion
id	internal diameter
IRR	internal rate of return
JI	joint implementation
kg	kilogram
km	kilometer
km^2	square kilometer
kPa	kilopascal
kt/yr	kilotonne/year
kW	Kilowatt
kWe	Kilowatt electrical
l/sec	Liters/second

m	meter
M$	Millions United States dollars
m^3	cubic meter
m^3CH_4	cubic meter of methane
m^3/s	cubic meter/second
m^3/t	cubic meter/ton
mD	millidarcy
MJ	Megajoule
mm	millimeter
mm^3	cubic millimeter
MPa	megapascals
Mt	megatonne
mton	metric tons (tonnes)
MVS	Mine Ventilation Services
MW	Megawatt
MWe	Megawatt electrical
MWh	Megawatt hour
MWth	Megawatt of thermal energy
N_2	nitrogen
NDRC	National Development and Reform Commission
NOx	nitrogen oxide
NPV	net present value
OM	operating margin
OPEX	operating expenditure
PDC	polycrystalline diamond
PVC	polyvinyl chloride
RMB	Renminbi (official currency of the People's Republic of China)
scf/t	standard cubic feet/ton
tCH_4	tonnes of methane
tCO_2e	tonnes of carbon dioxide equivalent
VAM	ventilation air methane
WHRB	waste heat recovery boiler

Acknowledgments

The Eastern Research Group, Inc. (ERG) Team, consisting of ERG, Ruby Canyon Engineering, and Harworth-East Limited, gratefully acknowledges the support of Inner Mongolia Tai Xi Group Coal Mines for providing valued access to information, personnel, and the coal mines during the course of this study. The team also acknowledges the project sponsor, the Coalbed Methane Outreach Program of the U.S. Environmental Protection Agency (EPA).

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EXECUTIVE SUMMARY

The Global Methane Initiative (GMI) is a voluntary, multilateral partnership that aims to reduce global methane (CH_4) emissions and to advance the abatement, recovery and use of CH_4 as a valuable clean energy source.[1] GMI achieves its goals by creating an international network of partner governments, private sector members, development banks, universities and non-governmental organizations in order to build capacity, develop strategies and markets, and remove barriers to project development for methane reduction, including coal mine methane (CMM) in Partner Countries.

Worldwide, coal mines are a significant source of emissions of methane, a gas that has a global warming potential 21 times greater than carbon dioxide (CO_2). A variety of mature technologies are available to utilize CMM, hence mitigating CH_4 emissions and taking advantage of its energy content. Due to the low cost of energy in many developing and developed countries, the capture and utilization of CMM is not always an economically attractive project. The Clean Development Mechanism (CDM) and Joint Implementation (JI) mechanisms create markets to monetize the emission reductions generated by greenhouse gas (GHG) emission reduction projects in developing countries and economies in transition. This additional carbon revenue has the potential to overcome the financial and technical barriers and financially incentivizes the mitigation of CMM emissions.

In 2009, as part of its commitment in support of the GMI (formerly the Methane to Markets Partnership), the U.S. Environmental Protection Agency's (EPA's) Coalbed Methane Outreach Program (CMOP) commissioned a feasibility study for a project involving CMM recovery and utilization in China.

Site Selection Process

The Eastern Research Group, Inc. Team (afterward referred to as "team" or "study team"), consisting of ERG, Ruby Canyon Engineering (RCE), and Harworth-East Limited (HEL), began this feasibility study in August 2009. The first stage in the process involved identifying potential mine sites in China as candidates for a technical and economic assessment and to conduct a pre-feasibility study of the most promising candidate mine(s).

The study team evaluated three coal mining groups in different regions of China to determine which site offered the best opportunity for a comprehensive CMM recovery and utilization feasibility study. The Inner Mongolia Tai Xi Coal Group (Tai Xi Group) coal mines near Alashan in Inner Mongolia, China were selected for the study based on a number of factors, including:

- High level of management interest in the proposed project.
- High coal production and CH_4 emission rates.
- Need for specialized CH_4 drainage as well as additional power generation and shaft air heat as the mines increase production.
- Safety and social benefits.
- Absence of CDM projects in the area.
- Interest and support expressed by Alashan City for the study.

The study team initially visited Alashan in Inner Mongolia in November 2009 to meet with the Tai Xi Group to develop future study plans. Subsequently, the team visited the site in January 2010 and

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[1] http://www.globalmethane.org/index.aspx

conducted tours of the underground and surface operations and facilities at four of the coal mines. A final visit was conducted in April 2010 and the findings were presented to the Tai Xi Group prior to submitting a pre-feasibility report.

Expanding on the earlier pre-feasibility study, this feasibility study was prepared as the second stage in the proposed project, and provides information about the Tai Xi Group's geographic and geologic setting, coal and CH_4 resources, mining techniques, and current power infrastructure. The study also evaluates the potential CH_4 liberation rate, assuming the planned 4.5 million metric tons (mtons) per year production target is met at the Tai Xi Group mines. In addition, the study determines the power required for effective CH_4 ventilation and drainage operations in order to achieve this tonnage by 2020. The proposed project's CH_4 capture and utilization options, and potential environmental and social benefits, are illustrated. Economic assessments are used to determine the internal rates of return for different options, both supported by the CDM or as a standalone project.

Overview of Tai Xi Group Mines

The Tai Xi Group mines are situated in Western Inner Mongolia in the Erdoaling mining area, located in the north-central Helan Mountains near the city of Alashan and the town of Zongbieli. The coal field concession contains high-quality anthracite coal in steeply dipping coal seams (45 to 80 degrees from horizontal).

Tai Xi Group consists of 14 closely spaced, individual reserve access drifts (i.e., sloping tunnels driven from the surface, which "drift" down through the strata to the coal reserves). These drifts have recently been consolidated into 12 individual closely-spaced, small coal mines, that have recently undergone technical and safety improvements. They span a total longitudinal distance of approximately 15 kilometers (km) in a crescent running parallel to the coal outcrop; each mine currently has a slim 1- to 2-km wide license area. The Tai Xi Group is expecting all of its small mines to be in full production by the end of 2020, when together they are projected to achieve a total annual production rate of 4.5 million mtons.

Table ES-1 shows the Tai Xi Group mines, their designed production capacity, in-place coal resource, expected recoverable coal tonnage, and the expected mine life based on documents provided by Tai Xi Group. Under current plans, the Tai Xi Group will recover 81.2 million mtons of the 105.9 million mtons in-place, representing 33 percent of the mining area's proven reserves. Eight of the 12 mines are relatively small (i.e., between 2 and 7 mtons), and six have a mine life less than 10 years. Of the remaining four mines, two of which—Xingtai and Song Shu Tan—contain 53 percent of the recoverable reserves, and are being newly constructed. For the purposes of this feasibility study, the team included all 12 mines forming the Tai Xi Group as one single site. The Song Shu Tan mine, with a recoverable reserve of 26.4 million mtons and a lifespan of 36 years, was chosen for the in-depth gas release analysis for this study.

Table ES-1: Tai Xi Group Mine Information

			Reserve, Megatonne (Mt)		
		Capacity, kilotonne per year (kt/yr)	**Geologic reserve**	**Recoverable reserve**	**Mine life (years)**
Active Mine					
1	Erdoaling Mine Xinyi Shaft	300	6.625	4.770	11.4
2	Hua Shi Quan Mine No.1 Shaft	300	2.604	2.104	5
3	Xing Tai Mine No.1 Shaft	300	5.156	4.179	9.95
4	Xing Tai Mine No.2 Shaft	300	3.642	2.884	6.87
5	Xing Tai Mine No.4 Shaft	300	8.443	6.869	16.4
6	Tan Yao Gou Mine	300	3.242	2.878	6.9
7	Dou Ya Gou Mine	300	2.786	2.320	5.5
8	Bie Li Gou Tuo Li Gou Mine	300	4.230	3.589	8.5
Subtotal		**2,400**	**36.728**	**29.592**	
Mines Under Technical Improvement					
1	Bie Li Gou Mine	300	13.130	11.424	27.2
2	Ha Sha Tu Mine	300	12.730	11.340	27
3	Xing Tai Mine	600	44.425	32.009	45.5
4	Song Shu Tan	900	35.565	26.404	36
Subtotal		**2,100**	**105.85**	**81.18**	
Total		**4,500**	**142.58**	**110.77**	

The mining region's transportation infrastructure relies completely on the network of roads. There is a modern, divided four-lane highway (two lanes in each direction) leading from Alashan to the mining region. Local truck traffic is expected to increase significantly when the mines are producing at full capacity, as the Tai Xi Group is planning to truck the entire 4.5 million mtons of coal per year from the mining region.

Gas Resource Assessment and Drainage Practices

This feasibility study is particularly timely for the Tai Xi Group, as Tai Xi Group's management already recognizes that CMM drainage will be required at all of its mines if the group is to safely achieve its production target. The CH_4 content of the primary seams forming Tai Xi Group's resource is very high, averaging 18.2 cubic meters per mton (m^3/mton) (583 square cubic feet per short ton [scf/t]). High specific emissions of up to 69 m^3/mton of coal mined have been recorded in the past, where coal seams above and below the working seam were being disturbed by the longwall mining method and gas was desorbing into the working area. This phenomenon is known as cross-measures CH_4 migration. Because the total target coal production for this group of mines has been set at 4.5 million mtons/year, large volumes of CH_4 will need to be drained to safely meet that target.

Total CH_4 release might reach 240 million cubic meters of methane per year (m^3CH_4/year), with an uncertainty range from 171 million to 307 million m^3/year, when the mines reach full production. Methane emission simulations show gas emission between 38 and 68 m^3/mton of coal mined.

The Tai Xi Group had previously attempted to pre-drain gas from the coal mines. The Tai Xi Group had attempted short-hole, in-seam pre-drainage, and an Australian company was carrying out long-hole drilling at one of the mines during the team's visits. Cross-measure drilling also has been used in an attempt to pre-drain gas from seams above the coal seam being mined. However, because the coal at the Tai Xi Group mines has very low permeability, less than 1 millidarcy (md), none of the current drainage systems provide adequate CMM drainage in sufficient time to enable coal recovery targets to be met safely. Instead, the feasibility study recommends the Tai Xi Group target the zones of increased permeability in the strata above and below the working area, which occurs once the coal has been extracted, the roof begins to cave in, and the floor begins to relax and fracture.

The study team carried out gas source and emission simulations, which show the introduction of hybrid cross-measures drilling into these zones will be the most effective method of gas drainage at the Tai Xi Group mines. This system should deliver at 40 to 50 percent capture efficiency for a fraction of the cost and with much less effort than is being expended on current pre-drainage methods.

In addition to gas captured via CH_4 drainage, the simulations show that high-powered surface ventilation fans must be installed to dilute the high levels of residual gas that will be released into each mine. There will be commensurately much higher electricity requirements to power this equipment compared to present, and a design capacity totaling in excess of 7.5 megawatt electrical (MWe) for ventilation will eventually be required. High electrical power demand for the CH_4 drainage pump stations, totaling about 6 MWe, also will be needed to remove the captured gas from the mines.

Drift air heating is essential to prevent access drifts and associated services such as water lines from freezing. The Tai Xi Group will require up to 31 MW of thermal energy (MWth) to keep the drifts from freezing when full production is achieved.

Evaluation of Coal Mine Methane Utilization Technologies

Given the anticipated increased electrical power demand related to the new mining activities (e.g., ventilation, CH_4 pumping), the study team recommends using CMM to fuel electrical generation plants. With the appropriate drainage techniques in place, Tai Xi Group's predicted high gas-release rate will produce sufficient CMM to fuel at least 20 MWe of power generation from high-efficiency generator sets (gensets).

Due to low ambient temperatures during winter months, heat provisions for mine shaft and onsite domestic heating represent a significant demand for coal combustion. To offset a portion of this demand, a fundamental component of the proposed project will be to recover heat from the onsite gensets using combined heat and power (CHP) applications. With an installed capacity of 20 MWe, the CHP system will supply 77,000 MW-hours (MWh) of heat energy during the 6-month heating season. This energy mix will allow for enhanced economics, electricity supply security, and the potential to greatly reduce internal coal consumption for local heating requirements.

As coal production is rapidly increased during 2011, some delay is expected before the CH_4 drainage systems can be fully implemented and grow to maturity. Packaged sections of the proposed gas utilization project will be rolled out concurrently with minimum delay as each mine's drainage system is introduced.

The CHP equipment should be installed in increments of 5 MWe each after the initial 15 MWe installation, based on the schedule outlined below and forecasted methane drainage rate in Figure ES-1.

- Phase 1: Initial installation of 15 MWe CHP equipment by 2012.
- Phase 2: Additional 5 MWe by 2014.
- Phase 3: Additional 5 MWe by 2016.
- Phase 4: Additional 5 MWe in, or around, 2018.
- Phase 5: Additional 5 MWe in, or around, 2020 for total CHP equipment installation of 35 MWe over 10 years.

In Phases 1 and 2 (2012 to 2014), the 20 MWe of CHP should be split between the three CH_4 drainage plants depending on the expected mining rates at each site. Once the gensets are commissioned, the CHP heat recovery equipment should be linked to an insulated hot water distribution network feeding heat to the relevant mines' intake drifts. Heat exchange equipment should have been constructed and commissioned at the intake air drifts concurrently with the CHP genset plant and the hot water network.

By 2013, the amount of pure CH_4 gas being drained will have increased to 38 million m^3/year or equal to at least 40 percent of all of the released gas. If coal recovery and gas drainage targets are met by 2015, Phase 3 of the proposed methane utilization project should be constructed for use in 2016. The remaining phases (i.e., Phases 4 and 5) are expected to be implemented based on actual coal and gas production. Where the available usable gas exceeds the installed capacity, any excess gas should be flared to reduce GHG emissions.

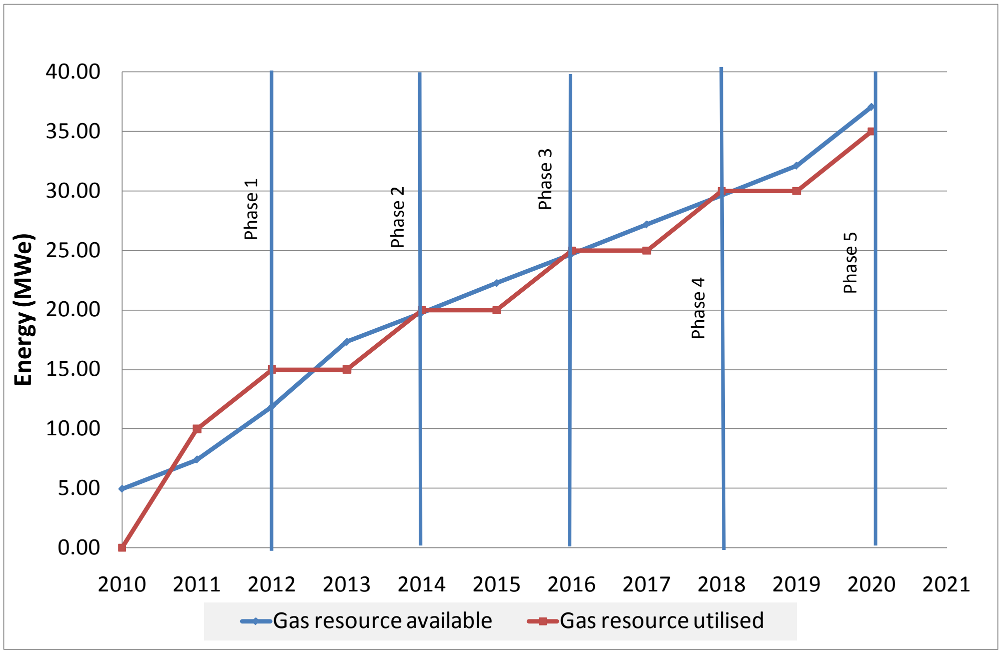

Figure ES-1: Expected Timing of the Installation of Power Generation in Phases as Coal Mining and Gas Production Increases

Additional CMM uses, such as for residential town gas, hot water and heat for mineworker bathhouses, heating of mine buildings, and use by local industrial facilities were explored. The seasonal demand for heat, however, would mean that for six months of the year where heat demand is low, the CMM-fired equipment would be shut down, resulting in poor CH_4 mitigation and project economics.

An analysis to project the ventilation air methane (VAM) concentrations within the Tai Xi Group mines was also performed. Ventilation system modelling has shown that VAM concentrations below 0.5 percent CH_4 are expected; at these low concentrations, VAM abatement projects are not economically attractive at current equipment costs and Certified Emission Reduction (CER) values.

Based on the study findings, it is recommended that three surface CH_4 extraction plants be constructed, with each plant aggregating CH_4 drainage from a number of small mines. The core proposed project should consist of 20 MWe in CHP format with space allowance for additional power generation equipment. The gensets should be logically sited (i.e., close to the CH_4 extraction plants, services, and the mine's inlet air drifts). A hot-water heat transport system should feed heat exchangers sited at the drift mouths. Any surplus heat should be directed toward the mines' buildings for heating and hot water. As the proposed project matures, surplus gas will become available and the course of action in incremental phases will be decided.

In summary, development of a CHP project at the Tai Xi Group mines will achieve several important benefits, including the following:

- Recovery and utilization of CH_4 will reduce annual CO_2 emissions by approximately 576,000 mtons CO_2 equivalent.
- Using CMM to generate power for ventilation and CH_4 pumping will help the Tai Xi Group mines meet their growing electricity requirements. When they reach full production, the mines and their general location are expected to demand at least 22.6 MWe.

- Using CMM for electricity generation will also help the mines achieve energy supply security. The mines are limited in their ability to import electricity (a maximum of 7 MWe) from the national power grid.
- Using waste heat recovery will enable the mines to save more than 10,000 mtons of coal combustion for mine air heating during six sub-zero temperature months of the year.

Project Economics

The proposed CMM utilization project illustrates different internal rates of return (IRRs) between choosing low-cost and low-efficiency domestic gensets or higher cost and high-efficiency gensets. The inclusion of CHP heat recovery systems, a gas grid, and gas storage, as well as the possibility of installing end-use co-firing burners as an option all contribute to lowering the IRRs and show that potential eligibility for carbon credits becomes much more probable, whatever the genset choice (i.e., meeting the additionality hurdle).

Capital and Operating Expenses. The pro-forma economic analysis is based on the installation of a high-efficiency CHP plant, installed at a cost of $819,000 per MWe.[2] Operating costs are assumed to be US$16/MWh. It is estimated that expenditures for the initial 10-MWe capacity will be spent in 2010, and that expenditures for installation of additional power generation will occur the year prior to activation.

Summary of CMM Recovery, Utilization and Capital and Operational Costs	
Type	**Cost**
Capture System CAPEX	US$2.25 million
Capture System OPEX (Labor)	15 personnel/300,000 mton/year
CHP Project CAPEX	US$819,000/MWe
CHP Project OPEX	US$16/MWh

Revenues. Revenue from the proposed project will take the form of avoided electricity imports and possible power exports, reduced coal combustion for mine air heating, reduced coal combustion in the thermal power plant, and CDM incentives. In addition, the CHP equipment would be robust and reliable enough to operate for more than 20 years, potentially saving money and offsetting CO_2 emissions for many years beyond the payback period.

Installation of a CHP project to offset coal consumption would equate to approximately 10,600 mtons/year of saleable coal, at a price of US$125/mton for the high-grade anthracite, for a **savings of US$1.3 million/year**.

Once the proposed project is operating at 20 MWe and 90 percent overall availability, calculations reveal the Tai Xi Group will avoid imports of some 157,680 MWh per year of electricity. The current tariff for imported electricity is 450 Renminbi (RMB) per MWh. This means that the mine would avoid approximately **US$10.6 million per year** over the proposed project's lifetime.

For mine air heating alone, every single ventilation air intake drift at the Tai Xi Group currently uses at least 360 mtons of anthracite per year. Once the group is producing 4.5 million mtons/year, this figure will increase to approximately 1,235 mtons of anthracite needed annually for every 300,000 mton/year

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[2] Based on a quote received from GE Jenbacher during the study.

unit. When projected across the group, this will equate to a total annual combustion of 18,500 mtons of anthracite, which at $125/mton, is **$2.3 million in annual savings**.

Emissions of more than 5 million mtons carbon dioxide equivalent (CO_2e) could be reduced from the baseline condition through 2020 should the project proceed as proposed. At US$8/mtons CO_2e that would be **US$40 million**, which would significantly enhance the project economics.

The table below shows the net present value (NPV) at three different discount factors, the IRR, and the time to pay back the investment (payout) of the proposed project cash flow under four scenarios:

- *Scenario 1: Full project implementation including CHP with CER sales.*
- *Scenario 2: Full project implementation including CHP with no CER sales.*
- *Scenario 3: Power generation only with CER sales and no CHP.*
- *Scenario 4: Power generation only with no CHP or CER sales.*

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
NPV @ 10%	$44,130,228	$4,011,118	$36,871,239	($1,727,038)
NPV @ 15%	$30,745,384	$1,388,787	$25,448,392	($2,795,856)
NPV @ 20%	$21,749,799	($275,214)	$17,788,574	($3,402,261)
IRR	72%	19.0%	64.7%	5.2%

Based on the revenue analysis, Scenarios 1 and 3 represent the highest returns and shortest payback periods. While the importance of CER sales in these scenarios resulted in the most favorable revenue, Scenario 2 (i.e., without CER sales) also provides favorable return on investment and a relatively short pay back due to the energy efficiency gains from the application of waste heat recovery. Only Scenario 4 (power generation and no CHP or CER sales) resulted in negative NPV.

Greenhouse Gas Emission Reductions

The reductions in GHGs attributed to the proposed project are two-fold: a) direct combustion of CMM at the mine by the power plant engines; and b) indirect reduction of power consumption purchased by the mine from more GHG-intensive (dominantly coal-fired) energy sources off the North China Power Grid (see Table ES-2).

The team estimates that by 2015, emission reductions totaling 554,816 mtons of CO_2e/year could be realized once the initial 20-MWe CHP project is operational. This total would increase to 951,113 mtons CO_2e after the addition of 15 MWe in 2013.

Table ES-2: Summary of Potential Tai Xi Group CMM Utilization Project Emission Reductions

Emission Reductions Measure	**Estimated Emission Reductions (Annually)**
Direct Methane Mitigation	452,255 mtons of CO_2e
Displacement of Fossil-Fueled, Grid-Imported Power	140,583 mtons of CO_2
Displacement of Fossil-Fueled Heat Generation	9,528 mtons of coal, and saving 21,203 mtons of CO_2 per heating season
Project Emissions	59,224 mtons of CO_2

Other Project Benefits

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

1.0 OVERVIEW

This feasibility study was sponsored by the U.S. Environmental Protection Agency (EPA) under the auspices of the Global Methane Initiative (GMI) (formerly Methane to Markets Partnership), of which both the United States and China are founding partners. The study was conducted by Eastern Research Group, Inc. (Massachusetts, United States), with support from Ruby Canyon Engineering (Colorado, United States) and Harworth-East Limited (United Kingdom).

1.1 Background

This feasibility study provides information about the Tai Xi Group's geographic and geologic setting, coal and methane (CH_4) resources, mining techniques, and current power infrastructure. The study also evaluates the potential CH_4 liberation rate, assuming the planned 4.5 million metric tons (mtons) per year production target is met at the Tai Xi Group mines. In addition, the study determines the power required for effective methane ventilation and drainage operations, in order to achieve this tonnage by 2020. The mines' CH_4 capture and utilization options, along with potential environmental and social benefits, are illustrated. Economic assessments are used to determine the internal rates of return (IRR) for different options, both supported by the Clean Development Mechanism (CDM) or as a standalone project.

1.2 Overview of Coal Mine Methane Drainage and Utilization in China

CMM recovery and utilization was started in China in the early 1990s as a strategy to enhance coal mine safety, diversify energy resources, and make use of a fuel that had been previously wasted. This was followed by the recognition of the greenhouse gas (GHG) mitigation potential of CMM recovery and use, as the Chinese government enacted a series of economic and administrative policies designed to encourage CMM utilization (Kerr, 2009).

China produces more hard coal than any other country in the world. In 2007, China mined 2,549 million mtons out of a total of 5,443 million mtons mined worldwide. This represents almost half of global total hard coal production. Approximately 95 percent of China's coal mining is performed using underground extraction methods.[3] Underground coal mining typically releases more CH_4 per mton of coal mined than opencast mining; this is due to the under- and over-mined seams of coal above and below the mined seam fracturing and releasing additional gas.

From the 2.42 billion mtons of coal extracted from underground mines in China in 2007, it is estimated that a total of 9.5 billion cubic meters (m^3) of methane were released. Most of this CH_4 is diluted to less than 1 percent in the ventilation air, known as ventilation air methane (VAM). The remaining methane is captured at higher concentrations through various underground drainage techniques. Chinese mining law recognizes the hazards that CH_4 gas presents in mines, and it sets out procedures to capture the methane either pre- or post-mining, before it is released into the atmosphere (see 7.0 Regulatory Issues).

CH_4 capture efficiency can be expressed as a "percentage capture" of all gas released from the system(s). This gas is mainly brought to the surface so the hazard is removed from the mine. Until recently, this gas was often released into the atmosphere. But now, China—along with many other

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[3] Of 2,549 million mtons mined in 2007, about 2,422 million mtons was removed from underground mines.

nations—has initiated a process of using the captured gas being brought to the surface, primarily for combustion-related activities. China, for example, will drain 5 billion m^3 and utilize 60 percent of this CMM by 2010 (NDRC, 2007).

1.3 Introduction to Tai Xi Group Mining Area

The Tai Xi Group coal mines are located in the Erdoaling mining area, with the location of the group's main office building at latitude of 39°05'10.48"N and a longitude of 106°03'20.65"E. The Erdoaling mining area is in the Helan Mountains, ranging from 1,800 to 2,400 meters above sea level, covers an area of about 64 square kilometers (km^2), and lies at the southern edge of the Gobi Desert (Figure 1.0). The climate is continental desert with cold, windy and dry winters, dust-laden springs, warm summers, and short autumns. Area precipitation is about 205 millimeters per year (8.1 inches/year).

Figure 1.0: Location of Tai Xi Group Mining Area

The mining district is located in the Inner Mongolia Autonomous Region, located approximately 47 kilometers (km) northeast of Alashan City (the capital of Alxa League with a population of approximately

200,000 and an area of 250,000 km^2), and approximately 64 km west of Wusutu, which is in Ningxia Hui Autonomous Region, the next closest large city.

The mining region's transportation infrastructure relies completely on the network of roads. There is a modern, divided four-lane highway (two lanes in each direction) leading from Alashan to the mining region. Local truck traffic is expected to increase significantly when the mines are producing at full capacity, as the Tai Xi Group is planning to truck the entire 4.5 million mtons of coal per year from the mining region. The nearest railroad to the mining area is approximately 23 miles away, over rugged terrain. The nearest commercial airport is at Yinchuan, the capital of Ningxia Hui Autonomous Region, approximately a 4-hour drive from Yinchuan to the mining properties.

1.4 Site Selection Process

The Tai Xi Group is a conglomerate of 12 closely-spaced, small mines that have recently undergone technical and safety improvements. They span a total longitudinal distance of approximately 15 km in a crescent running parallel to the coal outcrop; each mine currently has a slim 1- to 2-km wide license area.

The mines operated independently from 2002 to 2006. They were then closed and subsequently sold to the Tai Xi Group in July 2008. These individual mines have been consolidated under the Tai Xi Group in order to improve mine safety and productivity in this region of high-value anthracite coal. Although each small mine retains its original name and own manager, given their proximity to one another, small size, and shared technical services (i.e., headquarters sited centrally to the mines), it makes sense to deal with the group of mines collectively. The Tai Xi Group of mines includes:

<u>Active Mines</u>

- Erdoaling Mine Xinyi Shaft
- Hua Shi Quan Mine No.1 Shaft
- Xing Tai Mine No.1 Shaft
- Xing Tai Mine No.2 Shaft
- Xing Tai Mine No.4 Shaft
- Tan Yao Gou Mine
- Dou Ya Gou Mine
- Bie Li Gou Tuo Li Gou Mine

<u>Mines Under Technical Improvement</u>

- Bie Li Gou Mine
- Ha Sha Tu Mine
- Xing Tai Mine
- Song Shu Tan

The Tai Xi Group is expecting all of its small mines to be in full production by the end of 2020, when together they are projected to achieve a total annual production rate of 4.5 million mtons (see Table 1.7). The first of the reorganized mines was due to start production by the end of 2010.

High specific CH_4 emissions of up to 69 m^3 for each mton of coal mined have been recorded in the past. Because the total target coal production for this group of mines has been set at 4.5 million mtons/year, large volumes of CH_4 will need to be drained to safely meet that target.

Of the three mining group sites originally considered as potential feasibility study host sites, the Tai Xi Group was considered to be the most likely to proceed with project development. The Tai Xi Group also expressed a real need for technical analysis and support from outside the group and demonstrated a high level of interest and engagement in the process.

For the purposes of this feasibility study, the study team included all 12 mines forming the Tai Xi Group as one single site for the following reasons:

- Each small mine is contiguous to the next, essentially forming one zone of extraction, falling within an area some 15 km long by 5.5 km wide.
- The headquarters is central to the group of mines, where many of their shared services are being executed.
- The gas extraction plants will be shared among some of the mines.
- Production of 300,000 mtons/year proposed coal production at 10 of the mines is considered to be too small to support a CMM project in isolation.

In addition, Alashan City expressed interest and support for the study. Alashan City is located in an area comprised mostly of desert and includes a southern segment of the Gobi Desert. The mining region is situated in the Helan Mountain Range, and the Helan Mountain National Reserve, containing sensitive significant ecological and cultural resources, lies immediately east of the area, covering 261 square miles, with the highest peak measuring 11,700 feet tall.

After learning of the potential study to be funded by the EPA, local government officials at the county level initiated contact among the EPA, the Tai Xi Group, and officials from the city of Alashan, who have clearly stated that they are committed to environmental protection in the Alashan area.

The study team initially visited Alashan in Inner Mongolia in November 2009 to meet with the Tai Xi Group to develop future study plans based on the group's response to correspondence and information that was provided to them at the outset of the proposed project. Subsequently, the team visited the site in January 2010 and conducted tours of the underground and surface operations and facilities at four of the coal mines. A final visit was conducted in April 2010 and then findings were presented to the Tai Xi Group prior to submitting the pre-feasibility report.

The pre-feasibility report was based on the information gathered from site visits and ongoing information exchanges between the study team and the Tai Xi Group. The information gathered in the pre-feasibility study formed the basis for this feasibility study. During the mine visits, the team gathered the following information:

- Report by the Xi'an Research Institute of Coal Science that contains information on gas content and the pressure and permeability of the coal seams to be mined owned by Tai Xi Group.
- Numerous AutoCAD files of mine works and surface facility layouts.
- Stratigraphic cross-sections showing the relative position and thickness of the area's coal seams.
- Analysis of the mining methods used to extract the coal from the steeply dipping coal seams.

In addition, after the initial site visit, the Song Shu Tan mine, with a recoverable reserve of 26.4 million mtons and a lifespan of 36 years, was chosen for the in-depth gas release analysis for this study.

1.4.1 Geologic Setting

The Tai Xi Group coal mines are located in the Erdoaling mining area, with the location of the group's main office building at latitude of 39°05'10.48"N and a longitude of 106°03'20.65"E. The Erdoaling mining area is in the Helan Mountains, ranging from 1,800 to 2,400 meters (m) above sea level, covers an area of about 64 km^2, and lies at the southern edge of the Gobi Desert.

1.4.1.1 Stratigraphic Profile and Structural Geology

Strata of the Cambrian, Ordovician, Carboniferous, Permian, Triassic, Jurassic, and Quaternary time periods are present in the area (see composition below). The Helan Mountain Group is located nearby, but outside the Tai Xi mining area; the Helan Mountain Group contains mainly gneiss and granite gneiss with granite porphyry intrusions.

Time Period	Composition
Cambrian	Mostly limestone
Ordovician	Mostly dolomite
Carboniferous	Quartz sandstone, sandy mudstone, and some coal (although not commercial-quality)
Permian	Sedimentary rocks from mudstone to sandstone
Triassic	Sedimentary layers from shale to conglomerate in grain size
Jurassic	Commercial-quality coal
Quaternary	Alluvial gravel

The Jurassic series is made up of the Anding, Zhiluo, and Yan'an groups, the latter of which contains the commercial coal seams (Table 1.0). Figure 1.1 shows the coal section in detail.

Table 1.0: Stratigraphic Series of Interest in the Erdaoling Mining Area

Period	Formation	Symbol	Lithology
Quaternary		Q_1	Chong, alluvial gravel, sand, silt, located in depressions in the valley
		Q_1	Alluvial layer, calcareous cemented conglomerate
Jurassic	Anding	J_{3a}	The lower part is gray, gray-green fine-grained feldspar quartz sandstone, the upper part of the sallow feldspar quartz sandstone, gray-black shale, siltstone, and contact with the underlying integration
	Zhiluo	J_{2z}	Gray and yellow green quartz sandstone and shale, feldspar and quartz sandstone, shale, sandy shale
	Yan'an	J_{2y}	Gray - gray and white quartz sandstone, several layers of anthracite with an underlying unconformity

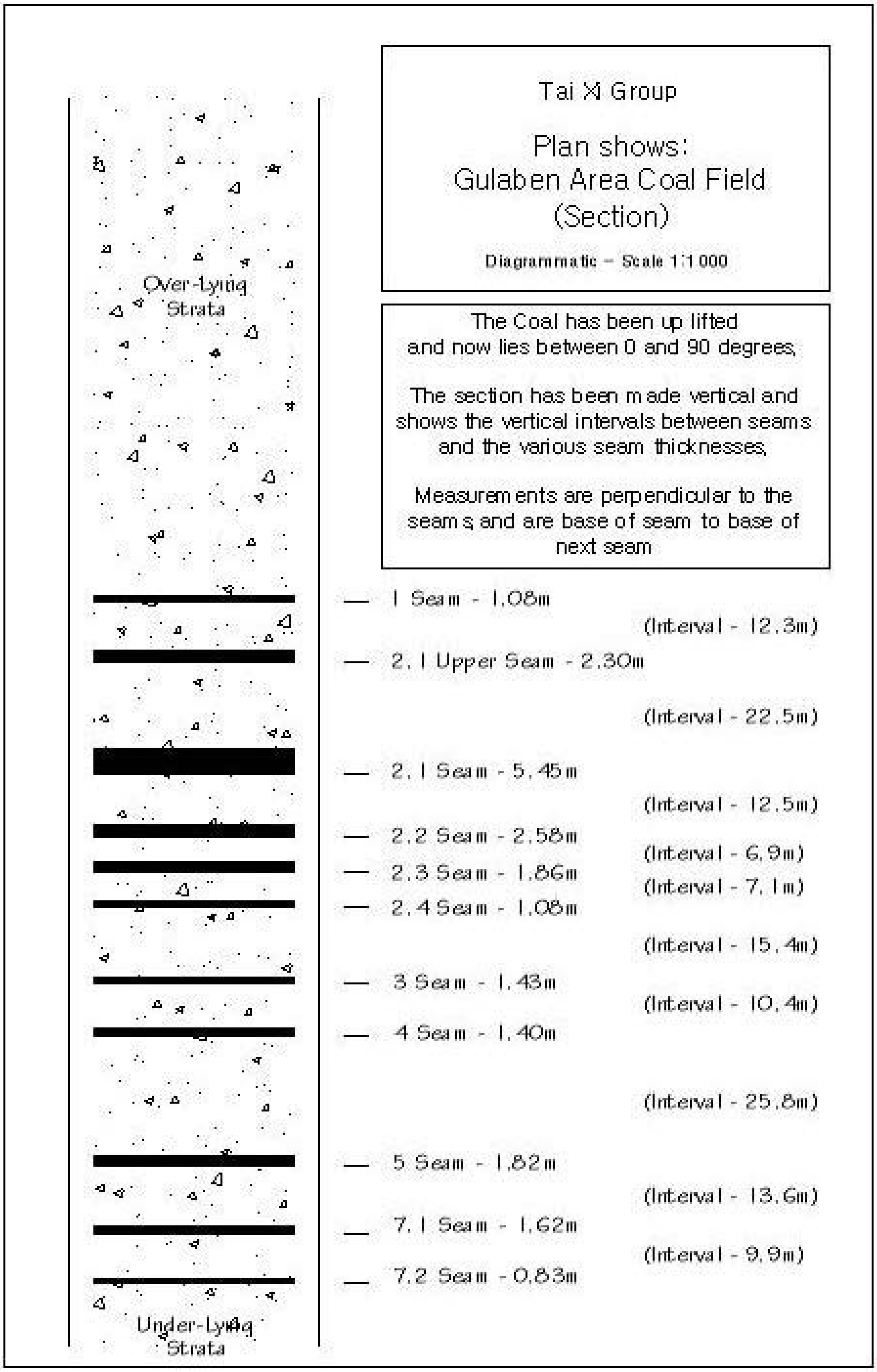

Figure 1.1: Erdaoling Area Coal Seam Section Diagram

The Erdoaling mining area lies within the Helan Mountain fault/fold belt. Figure 1.2 shows a series of east-northeast trending series of synclines and anticlines, with the mining properties lying on the south limb of a syncline dipping steeply to the northwest. In the mining area, the strata dips from 45 to 80 degrees.

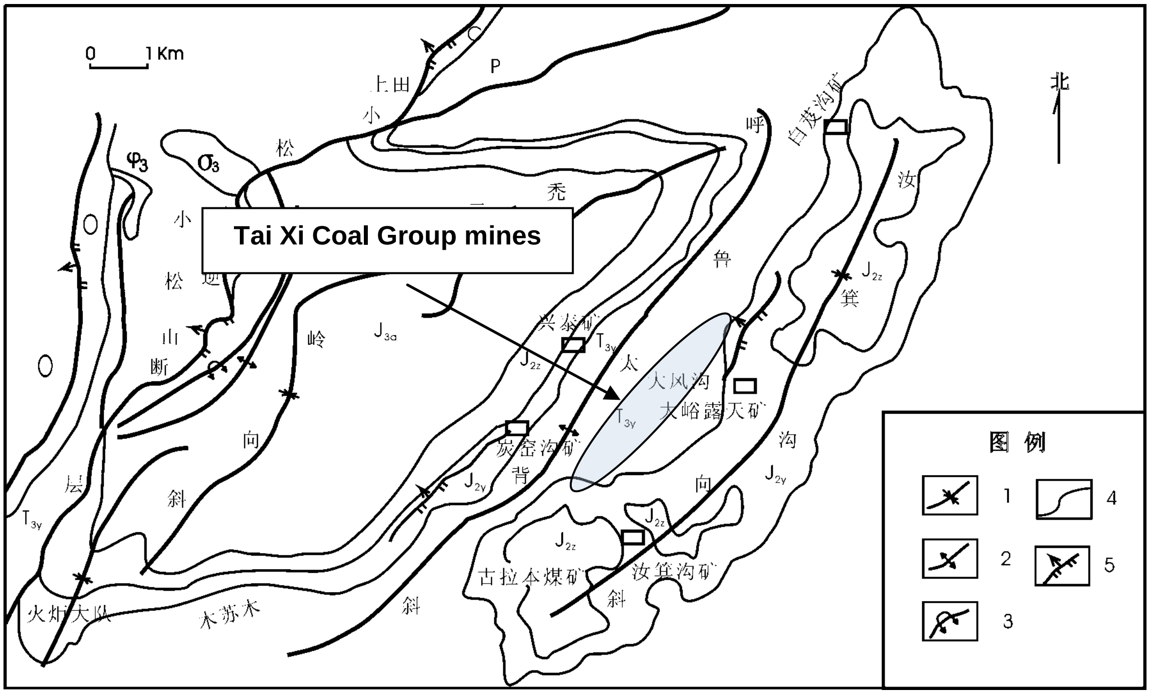

Figure 1.2: Regional Geology Map Erdaoling Mining

1 – Syncline; 2 – Anticline; 3 – Inverted syncline; 4 – Thrust fault; 5 – Stratigraphic boundary; J_{3a} – Upper Jurassic Anding Formation; J_{2z} - Middle Jurassic Zhiluo; J_{2y} – Lower Jurassic Yan'an; T_{3y} – Upper Triassic group; P – Permian; C – Carboniferous; O – ; φ_3 – Yanshanian basic rock; σ – Caledonian ultrabasic rock

A total of nine reverse faults exist within the mining area, with displacements from less than 10 to 80 m. Figure 1.3 shows the coal outcrop, mine shafts, and structural features in the Erdaoling Mining Area.

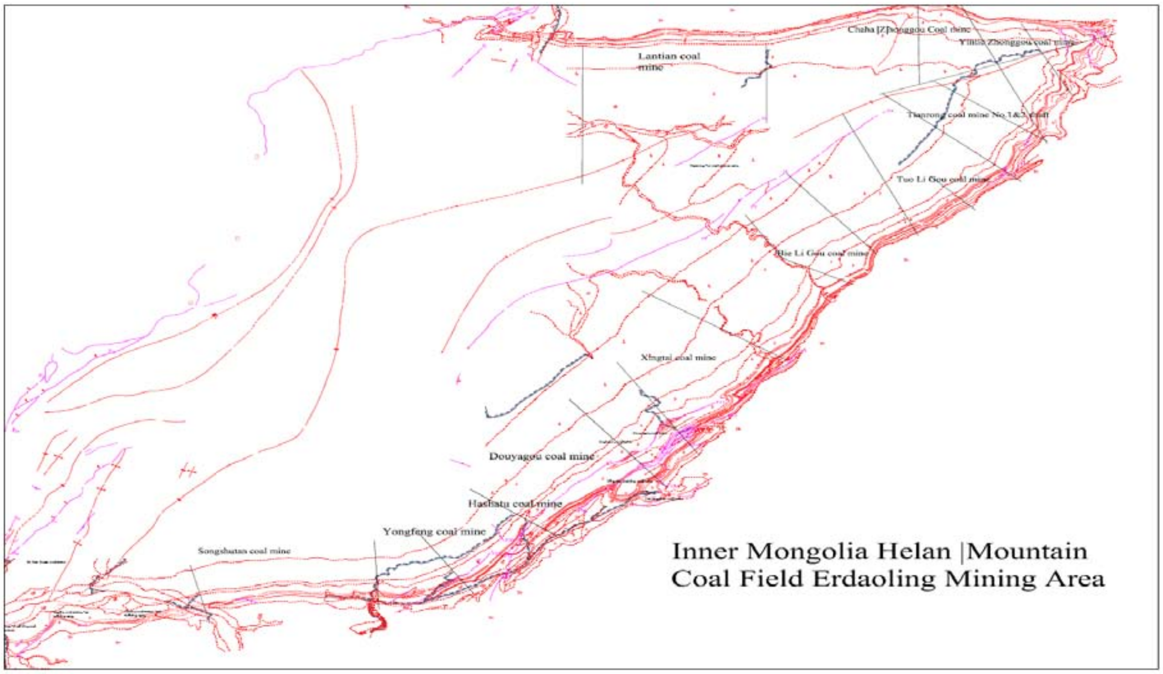

Figure 1.3: Map Showing Coal Outcrop, Mine Shafts and Structural Features in the Erdaoling Mining Area

Figure 1.4 shows a northwest to southeast structural cross-section of the area. Magmatic activity in the region and the resulting high paleotemperature metamorphosed the coal from bituminous to anthracite.

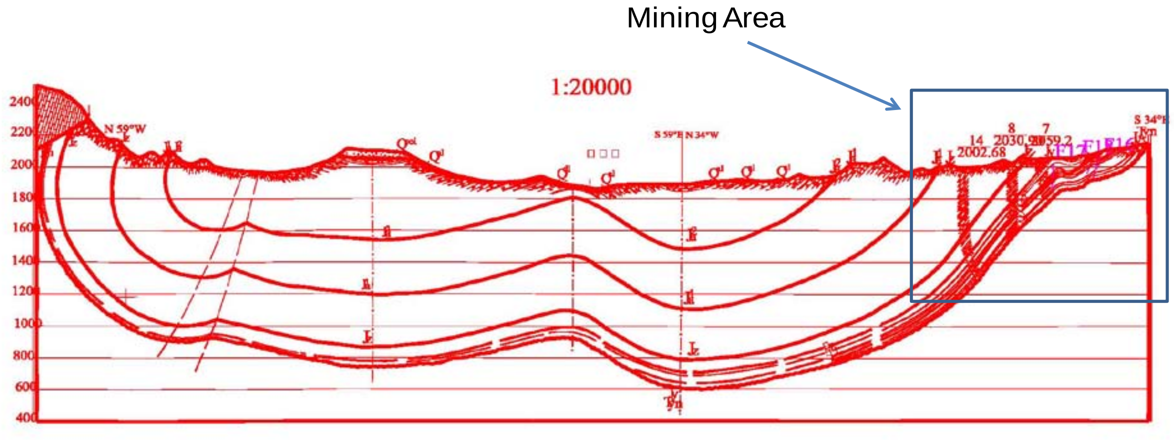

Figure 1.4: A Northwest to Southeast Structural Cross-Section of the Erdaoling Mining Area

A July 2007 report by the Xi'an Research Institute of Coal Science details the sampling and testing conducted to determine the Tai Xi Group coal characteristics (e.g., CH_4 content, pore pressure, permeability to gas flow).

A total of 10 boreholes were drilled directly into the coal (up dip) from the return airways being developed in the Song Shu Tan mine at elevations of 1,500 and 1,600 m above sea level. Eight were drilled in what will be the initial mining area, and two were drilled at a further location. Two boreholes (one at each elevation) were drilled into the 2-1 upper, 2-1, 2-2, and 2-3 seams. Two remote boreholes were drilled into the 2-1 seam at the two elevations (Figure 1.5).

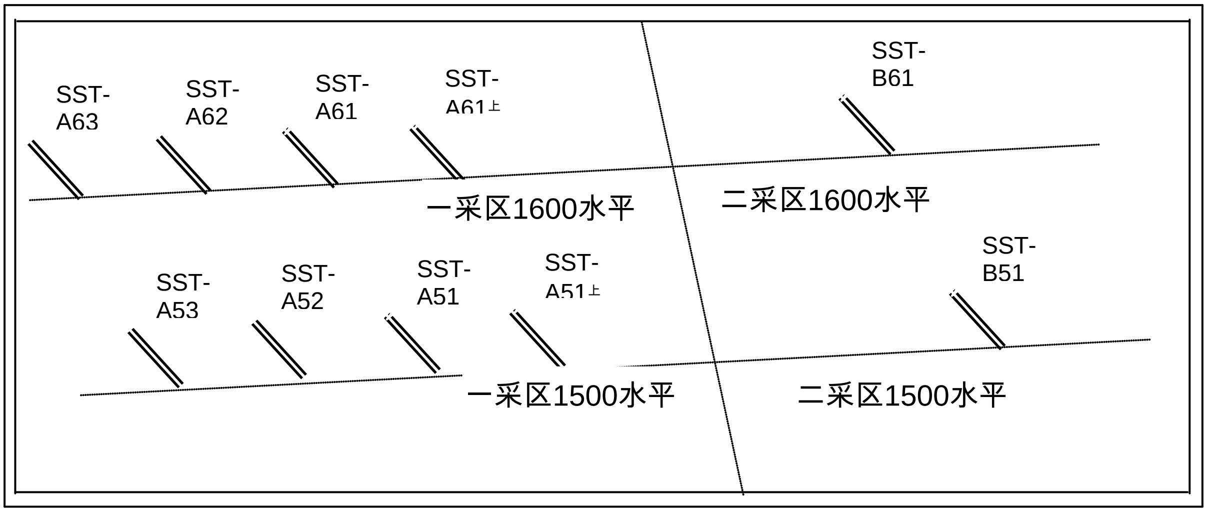

Figure 1.5: Picture of Relative Positions of Coal Test Boreholes

Table A-1 in the Appendix contains the details of the boreholes, including angle, depth, length of core, and diameter. Table 1.2 shows the average moisture, ash, volatile matter content, carbon content, vintrinite reflectance, and density of the #2 seam group. All parameters fit within the requirements for classifying the coal as anthracite. Table 1.3 presents some pertinent coal characteristics in terms of adsorbed methane content, gas composition, Langmuir adsorption parameters, measured pore pressure, and calculated permeability.

Table 1.2: General coal characteristics of the #2 seam group

Seam	Moisture, %	Ash, %	Volatiles, %	Carbon, %	Vitrinite Reflectance, %	Density, g/cm^3
2-1 upper	0.65	3.95	7.13	NA	NA	1.47
2-1	0.56	6.63	8.32	80.7	2.37	1.49
2-2	0.59	6.64	6.68	78.8	2.1	1.48
2-3	0.66	9.29	6.53	81.9	2.25	1.49

Table 1.3: Average Gas Content, Composition, Langmuir Isotherm Values, Seam Pressure and Permeability Values

Seam	CH_4, m^3/ mton	%CH_4	% Carbon Dioxide (CO_2)	% Nitrogen (N_2)	VL, m^3/mton	PL, megapascals (MPa)	Pressure, MPa	Permeability, millidarcy (mD)
2-1 Upper	17.76	92.4	0.3	7.4	26.34	0.53	0.690	0.835
2-1	17.50	87.4	0.3	12.3	23.60	0.57	0.585	1.165
2-2	21.93	90.1	0.6	9.3	24.55	0.67	0.775	0.069
2-3	16.32	84.0	0.7	15.3	24.29	0.55	0.525	0.374

Based on the coal content values contained in Table 1.3, the Tai Xi Group can expect very high-gas-content coal with significant near mine-face pore pressure and low- to very low-permeability. Once the effective permeability of the coal is enhanced by fracturing related to mining, large gas emissions should be expected.

Additional tables conveying coal seam characteristics can be found in the Appendix (see Table A-2).

1.4.2 Coal and Methane Resources

1.4.2.1 *Mining Area Resources*

The Tai Xi Group mining area contains high-grade anthracite coal, which has a high-carbon and high-heat-content that burns with a smokeless, short blue flame. It is a relatively rare resource that commands a regional price of US$125/mton and can be used instead of coke to fire steel manufacturing furnaces.

There are 11 major seams in the coal deposit sequence, all spaced within a band of strata approximately 160 m thick. Within this band, the average total coal thickness is 17.01 m, indicating a considerable coal seam concentration. Coal seam mining characteristics, such as partings and roof/floor lithology, are shown in Table 1.4.

Table 1.4: Coal Seam Mining Characteristics

Seam	Average thickness (m)	Spacing (m)	Structure	Parting layers	Roof	Floor
1	1.08	NA	NA	NA	NA	NA
2-1 upper	1.72	30	NA	NA	NA	NA
2-1	5.06	17	Simple	1 to 5	Siltstone	Fine sandstone
2-2	1.92	19	Complex	3 to 7	Fine sandstone	Siltstone
2-3	1.76	5	Simple	1	Siltstone	Siltstone
2-4	0.96	6	Simple	1	Siltstone	Siltstone
3	1.27	14	Simple	1	Siltstone	Siltstone
4	1.15	9	NA	NA	NA	NA
5	1.23	24	Simple	1 to 2	Siltstone	Siltstone
7-1	1.25	12	Simple	1	Siltstone	Fine sandstone
7-2	0.69	9	NA	NA	NA	NA

NA: not available

Most of the current mining plans target the 2-1 upper and 2-1 seams (shown in Figure 1.1) to be mined first because they are the most regionally consistent in thickness and contain 57 percent of the proven coal resource. The Xingtai #2 mine has targeted the 7-2 seam to be mined first because of its local thickness. Table A-2 in the Appendix shows the breakdown of coal and gas reserves in the Erdoaling area (based on a 2002 report on coal and methane resources in the Erdoaling mining area).

The proven coal resource in the area is 247 million mtons out of a total estimated resource of 1,026 million mtons. The total proven methane resource is 2,565 million m^3 out of an estimated total resource of 18,332 million m^3. Tables 1.5 – 1.5d show the coal and gas reserves by category and by seam.

The reserve categories in the tables are as follows:

A – Proven or presumptive reserves. These reserves have a high degree of certainty and are well defined by drilling, mining for the coal resource, and sampling gas content for the gas resource. These volumes are 600 m or less in depth.

B – Probable or inferred reserves. These reserves have a moderate degree of certainty and are between 600 and 1,000 m.

C – Possible or forecast reserves. These reserves have a low level of certainty based on drilling and sampling and occur at depths of between 1,000 and 1,500 m.

D – Potential reserves. These reserves are based on extrapolation of data to poorly explored and sampled areas and occur at depths between 1,500 and 2,000 m.

Table 1.5: Total Yanan Coal and Gas Resource in Erdoaling Area			
Class	**Gas Content (m^3/t)**	**Coal Resource (Mt)**	**Gas Resource (mm^3)**
A, Proven	10.37	247	2,565
B, Probable	17.40	174	3,025
C, Possible	18.31	247	4,526
D, Potential	23.00	357	8,216
Total		1,026	18,332

Table 1.5a: Coal and Gas Resource in the 2-1 Seam in Erdoaling Area			
Class	**Gas Content (m^3/t)**	**Coal Resource (Mt)**	**Gas Resource (mm^3)**
A, Proven	12.5	118	1,463
B, Probable	16.4	63	1,031
C, Possible	20.5	77	1,573
D, Potential	23.0	14	314
Total		271	4,382

Table 1.5b: Coal and Gas Resource in the 2-2 Seam in Erdoaling Area			
Class	**Gas Content (m^3/t)**	**Coal Resource (Mt)**	**Gas Resource (mm^3)**
A, Proven	11.6	31	365
B, Probable	16.7	21	355
C, Possible	20.7	21	425
D, Potential	19.0	2	30
Total		75	1,175

Table 1.5c: Coal and Gas Resource in the 2-3 Seam in Erdoaling Area			
Class	**Gas Content (m^3/t)**	**Coal Resource (Mt)**	**Gas Resource (mm^3)**
A, Proven	13.6	31	424
B, Probable	18.5	11	212
C, Possible	22.0	10	225
D, Potential		0	0
Total		53	861

Table 1.5d: Coal and Gas Resource in the 2-4 Seam in Erdoaling Area			
Class	**Gas Content (m^3/t)**	**Coal Resource (Mt)**	**Gas Resource (mm^3)**
A, Proven	10.4	30	317
B, Probable	14.2	2	27
C, Possible	16.0	1	21
D, Potential		0	0
Total		34	365

1.4.2.2 Tai Xi Group Coal Resources

Coal production is planned to rapidly increase during 2011, and the mines are planned to be in full production of 4.5 million mtons/year by the end of 2020. This rapid expansion will be a huge undertaking, and the Tai Xi Group will need every resource available. This document will play a vital role in obtaining investment for the proposed CH_4 end-use project.

Table 1.6 shows the Tai Xi Group mines, their designed production capacity, in-place coal resource, expected recoverable coal tonnage, and the expected mine life based on documents provided by the Tai Xi Group. Under current plans, the Tai Xi Group will recover 81.2 million mtons of the 105.9 million mtons in-place, representing 33 percent of the mining area's proven reserves. Eight of the 12 mines are relatively small (i.e., between 2 and 7 mtons), and six have a mine life less than 10 years. Of the remaining four mines, Xingtai and Song Shu Tan, which contain 53 percent of the recoverable reserves, are being newly constructed. The Song Shu Tan mine, with a recoverable reserve of 26.4 million mtons and a lifespan of 36 years, was chosen for the in-depth gas release analysis for this study.

Table 1.6: Tai Xi Group Mine Information

			Reserve (Mt)		
		Capacity (kt/yr)	**Geologic reserve**	**Recoverable reserve**	**Mine life (years)**
Active Mine					
1	Erdoaling Mine Xinyi Shaft	300	6.625	4.770	11.4
2	Hua Shi Quan Mine No.1 Shaft	300	2.604	2.104	5
3	Xing Tai Mine No.1 Shaft	300	5.156	4.179	9.95
4	Xing Tai Mine No.2 Shaft	300	3.642	2.884	6.87
5	Xing Tai Mine No.4 Shaft	300	8.443	6.869	16.4
6	Tan Yao Gou Mine	300	3.242	2.878	6.9
7	Dou Ya Gou Mine	300	2.786	2.320	5.5
8	Bie Li Gou Tuo Li Gou Mine	300	4.230	3.589	8.5
Subtotal		**2,400**	**36.728**	**29.592**	
Mines under technical improvement					
1	Bie Li Gou Mine	300	13.130	11.424	27.2
2	Ha Sha Tu Mine	300	12.730	11.340	27
3	Xing Tai Mine	600	44.425	32.009	45.5
4	Song Shu Tan	900	35.565	26.404	36
Subtotal		**2,100**	**105.85**	**81.18**	
Total		**4,500**	**142.58**	**110.77**	

Based on the document “Basic Information of the Tai Xi Group,” plans are underway to construct new mines that will fill the production gap expected to occur beginning in 2018. Table 1.7 shows the available production data for seven of the mines from 2005 to 2007.

Table 1.7: Available Coal Production Data for Mines in the Tai Xi Group (mtons)

Mine Name	**Year**		
	2005	**2006**	**2007**
Erdoaling	158,000	135,700	177,700
Hua Shi Quan	74,000	76,000	17,500
Bie Li Gou Tuo Li Gou	107,600	100,000	36,800
Xing Tai #1	237,400	176,700	20,700
Xing Tai #2	155,600	183,600	77,500
Tan Yao Gou	185,600	181,200	88,900
Dou Ya Gou	181,300	136,800	85,900

The current Tai Xi Group coal production forecast is shown in Table 1.8.

Table 1.8: Current Coal Production Forecast for the Tai Xi Group

Year	**Coal Production (mtons)**
2010	0.75
2011	1.5
2012	1.8
2013	2.1
2014	2.4
2015	2.7
2016	3
2017	3.3
2018	3.6
2019	3.9
2020	4.5

1.4.3 Mining Technique

Under the Tai Xi Group, the mines will employ longwall retreats that use specially designed roof supports, drilling and blasting, and simple gravity loading (Figure 1.6). The coal face length of these long walls is just 70 m; thus, for the remainder of this study, the coal faces shall be referred to as “shortwalls.”[4] The low level of mechanization within these mines is expected to result in an unusually low energy demand for mineral handling relative to conventional longwall operations.

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[4] Typical longwalls are approximately 300 m in length.

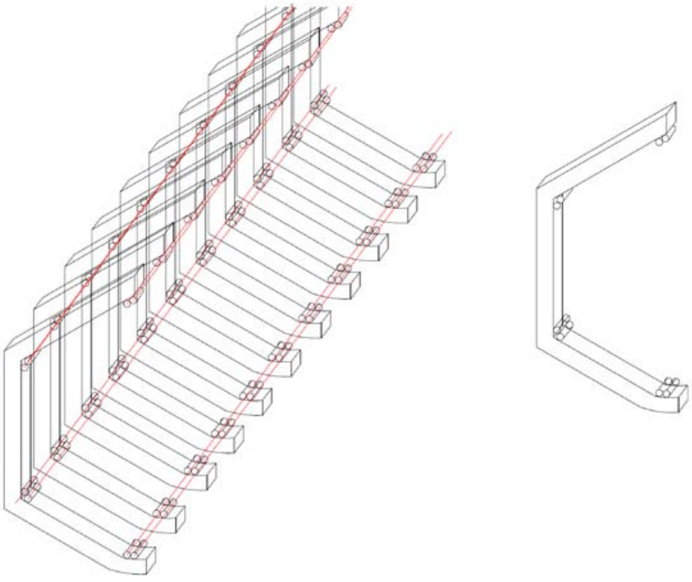

Figure 1.6: Method of Coal Face Roof Support

1.4.4 Mine Ventilation

The shortwalls are ventilated using a conventional “U” system, with return air emitted to the rise (upper roadway) and the coal removal in the lower intake. When calculating the amount of ventilation required on the coalface, an average 1 percent methane dilution level in the return roadway ventilation air has been used. See Figure 1.7 for a diagram of the roadway layout and the coalface ventilation method.

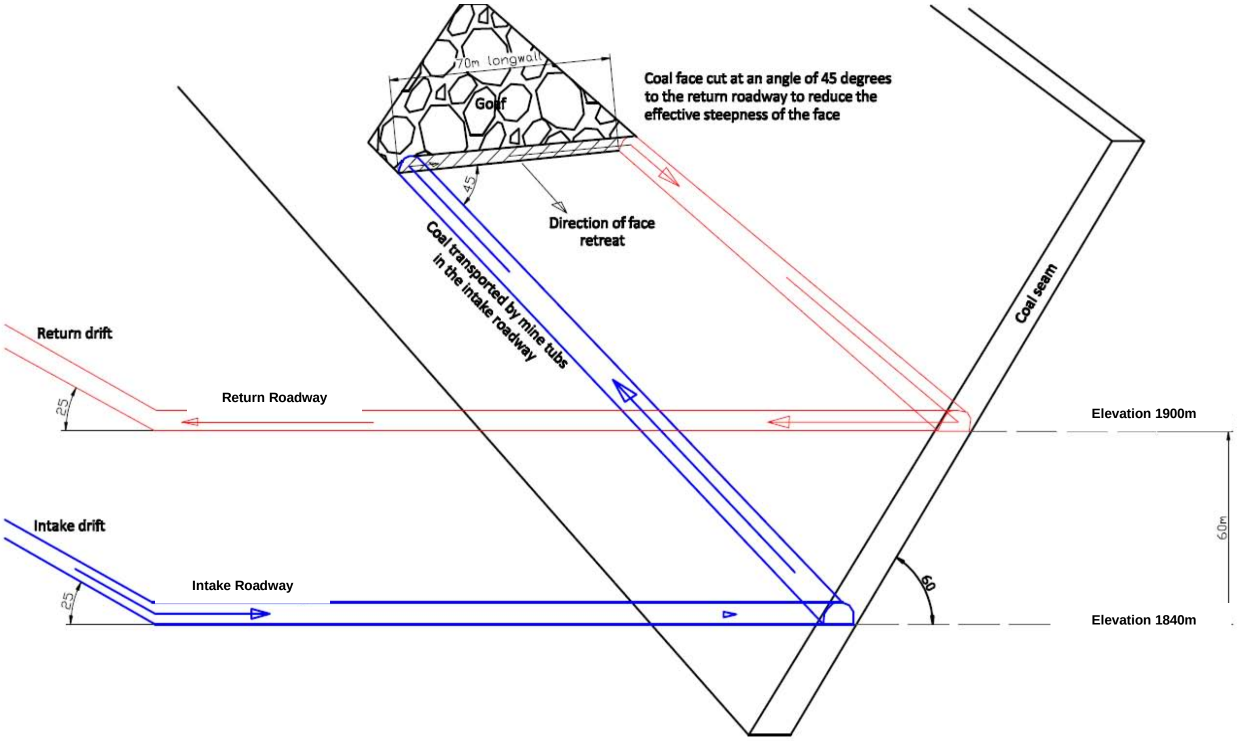

Figure 1.7: Method of Mining and Coal Face Ventilation

All ventilation in the small mines is achieved using surface exhaust fans. Air is drawn through the mines via the low pressure created by these surface fans, and all 12 mines have at least one dedicated return air drift. Typically, at around 33 cubic meters per second (m^3/s) per proposed 300,000 mton/year unit, the ventilation air currently being drawn into the mines represents about one-third of the ventilation rate that will be required once the Tai Xi Group coal mines reach full production.

The current fan power of each mine is listed in Table 1.9 and shows a total of around 1.5 megawatts (MW) for the group. This level of equipment is currently able to achieve about 500 m^3/s total airflow. This airflow is used for general ventilation duties only and is not exhausting much. However, once production commences, airflow into the mines will need to be increased to at least 100 m^3/s per 300,000 mton unit in order to dilute the predicted released gas to safe levels. A total airflow of around 1,500 m^3/s will be required once production reaches 4.5 million mtons/year.

Table 1.9: Current Surface Fans at Tai Xi Group Mines*

Number	Name	Mine Name	Present Surface Fan Details	Kilowatts (kW) of installed power
1	Main drift	Tuo Li Gou	45 x 2	90
2	Main drift	Xing Tai	55 x 2	110
3	Deputy drift			
4	North area drift			
5	Main Drift	Dou Ya Gou	55 x 2	110
6	Main drift	Tan Ya Gou	45 x 2	90
7	Main drift	Ba Xian Gou	(if "shalin1" then 2x90)	180
8	Main drift	Gu La Ben	(if "shalin4" then 2x90)	180
9	Main drift	Bei Li Gou	55 x 2	110
10	Deputy drift			
11	Main drift	Ha Sha Tu	30 kW and 45/55 kW radial	55
12	Main drift	Chang Gou	new mine (estimate 2 x 55kW)	110
13	Drift A	Song Shu Tan	2 x 160	320
14	Drift B			
15	Main drift	Hua Shi Quan	unknown (estimate 2 x 55kW)	110
			Total present installed power	**1465**

**Data obtained from verbal discussions with engineers at Tai Xi in April 2010; where there are multiples, the two fans are arranged in series to generate pressure. Generally, there are identical standby fans at each site.*

Notably, the multiple drift entries for ventilation into the combined total of Tai Xi Group's mines appear to deliver airflow at a much lower power requirement than the more traditional large mine twin shaft ventilation system.

Figure 1.8 shows a simplified ventilation model of a shortwall, 300,000-mton/year mine at Tai Xi Group.

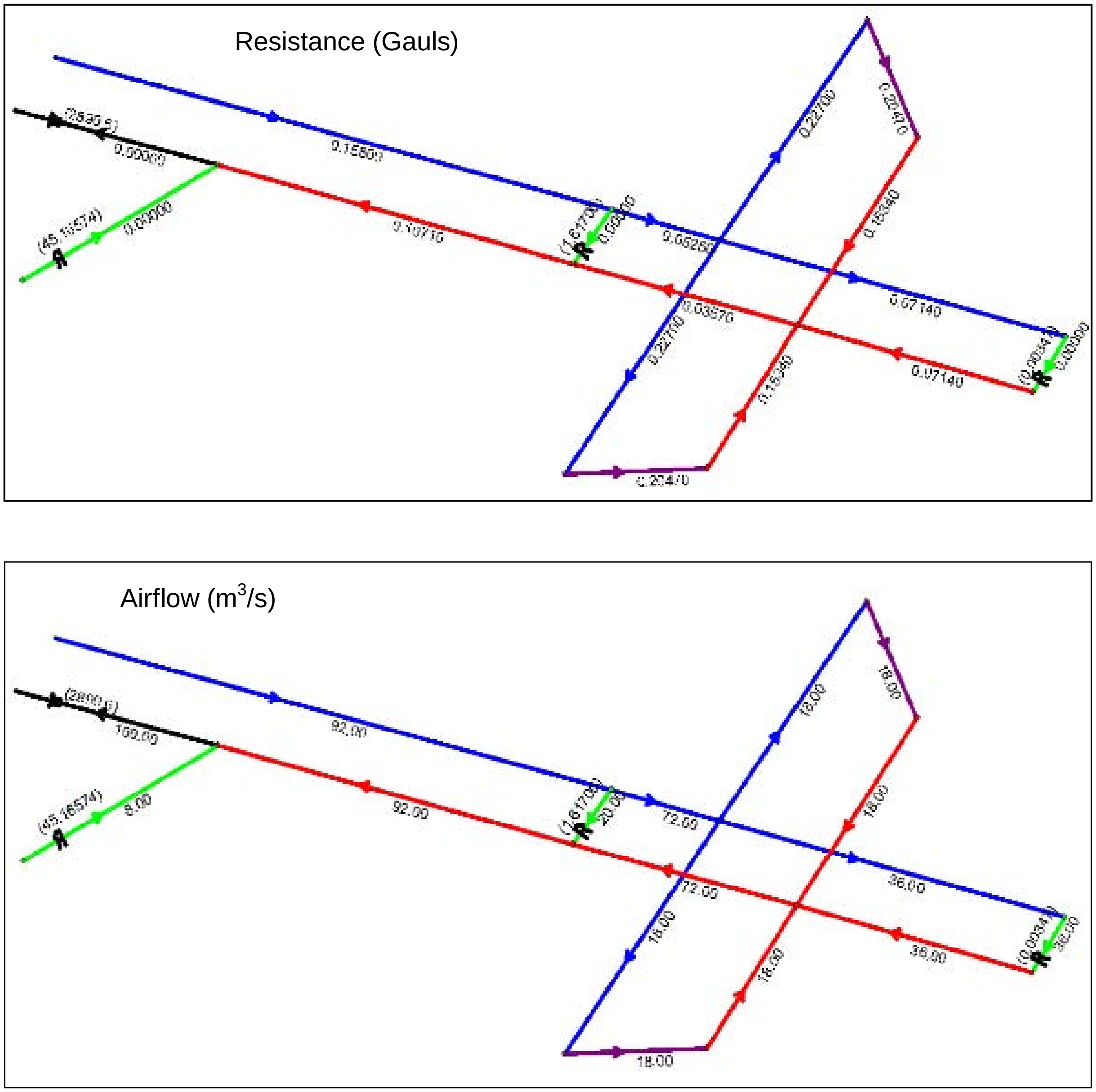

Figure 1.8: VNet PC Ventilation Model Used to Calculate the Required Mine Ventilation Power

Drift air heating is essential to prevent access drifts and associated services such as water lines from freezing up. The study team estimated the Tai Xi Group will require up to 31 MW of thermal energy (MWth) to keep the drifts from freezing when full production is achieved. Figure 1.9 shows the current shaft heating arrangement.

Figure 1.9: Example of Current Ventilation Drift Heating Arrangements

1.4.5 Drained Gas Resource Assessment

A number of factors, including the following, indicate that considerable quantities of gas will be released during mining:

- High gas content of the coal seams
- Close proximity (concentration) of the coal seams
- Adoption of total caving mining method (shortwall)
- Rate of coal to be mined

The coal at Tai Xi Group mines has a high intrinsic gas content, averaging 18.2 m^3/mton across all seams and ranging from 13.9 to 22.7 m^3/mton (see Table A-3 in the Appendix).

The study team calculated a total CH_4 release might reach 240 million cubic meters of methane per year (m^3CH_4/year), with an uncertainty range from 171 million to 307 million m^3/year, when the mines reach full production. Methane emission simulations show gas emission between 38 and 68 m^3/mton of coal mined (see Table A-3 in the Appendix).

Currently, one active pump station drains gas from the Song Shu Tan and Ha Sha Tu mines. As part of the study, the team installed an orifice plate flow meter and recorded readings shows a total gas flow of approximately 118 liters/second (360 thousand cubic feet per day) and a 20 percent CH_4 concentration. All drained gas is currently being vented to the atmosphere.

The Tai Xi Group currently employs three types of CH_4 drainage: cross-measures, short-hole in-seam, and long-hole in-seam, none of which has been extensively deployed or exhibited recognizable success in degassing the coal prior to mining.

1.4.6 Current Power Infrastructure

The Tai Xi Group mines currently have an electrical power requirement of approximately 4.5 MWe. Other industry and villages nearby currently have a power requirement of approximately 5.5MW. In total, the local area currently has a total electrical power demand of 10 MWe.

At Tai Xi Group, there is an 18-MWe coal-fired power plant consisting of three 6-MWe steam turbo gensets fueled by waste coal from their mines. Generally, two turbines are in operation to satisfy the local area's demands, and the third turbine is kept in standby/maintenance mode. Incoming supplies from the Inner Mongolia power grid can supply an additional 7 MWe to the local power grid; however, supplemental supplies are only used if the local coal-fired power plant is shut down.

Once Tai Xi Group is producing 4.5 million mtons of coal per year by the end of 2020, on-site demand is calculated to be at least 22.6 MWe, creating a total local demand of at least 28.1 MWe. The Tai Xi engineers predict the thermal power plant cannot be expanded any further. The condensing-type turbines are dependent upon the local water supply for their evaporative cooling towers so when the plant is operating at a full 18 MWe, the water supply is stretched to the limit. This indicates a capacity shortfall will occur unless the Tai Xi Group can upgrade the incoming national power grid supplies. Figures 1.10 and 1.11 show the thermal power plant at Tai Xi Group.

Figure 1.10: 18-MWe Thermal Power Plant for the Erdoaling Mining Area

Figure 1.11: 6-MWe Steam Turbine in Coal Fired Power Plant in Erdoaling Area

1.5 Recommendations for Coal Mine Methane Drainage

Tai Xi Group management stated a majority of the technical and safety improvement works to be completed by the end of 2010, at which point commercial-scale coal production would commence. Production was expected to reach a rate of 0.75 million mtons/year by the end of 2010. Production is then forecast to increase through 2020 in a fairly linear manner, to a maximum rate of 4.5 million mtons/year by the end of 2020.

Based on study findings, the team made the following preliminary recommendations for CMM drainage and capture at the Tai Xi Group mines. For a detailed examination of CMM capture and utilization, please see Sections 4 and 5, respectively.

- Because of the high gas content of the coal sequence, cross measures for CH_4 drainage will be required on each coalface within the mining group, and ventilation alone will not be enough to dilute the high rates of gas being released to safe levels. Steel pipelines must also be installed throughout the mines, leading from the shortwalls to the surface[5] (see Figure 1.12).

- Before the drilling of any boreholes, CH_4 extraction vacuum plants must be constructed on the surface of the mines with sufficient capacity to extract all of the captured CH_4 while maintaining sufficient vacuum at the boreholes on the shortwall.

- To avoid long pipeline distances over the rugged terrain, it is predicted at least three surface methane extraction vacuum plants will be required. One is already installed and operational at the Song Shu Tan main drift in the southern part of the mining area but will eventually need upgrading from 180 kW to 2,000 kW installed power to enable the forecasted drainage volumes to be accomplished. Another extraction plant should be installed near the Xing Tai main drift in

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[5] Pipelines should be constructed of steel instead of polyvinyl chloride (PVC), which can generate static electricity.

the center and at least a third at the Bei Li Gou deputy drift in the northern section of the mining area. These three plants should each be designed to cover an equal share of the Tai Xi Group's production (i.e., each plant should drain gas from 1.5 million mtons/year of shortwall coal mining activity).

- Once the pipelines and vacuum plants are commissioned, cross-measure holes can then be drilled to the specification detailed in this study.

At the time of this feasibility study, the Tai Xi Group had not confirmed its final design configuration of the CH_4 drainage system. The primary reason for this lack of confirmation was because they were experimenting with pre-drainage using long hole drilling and did not expect the large quantities of gas that the study team predicted would be encountered post-mining. As a result, Tai Xi Group installed drainage pipe that was too small in diameter to adequately carry the volumes predicted by the study.

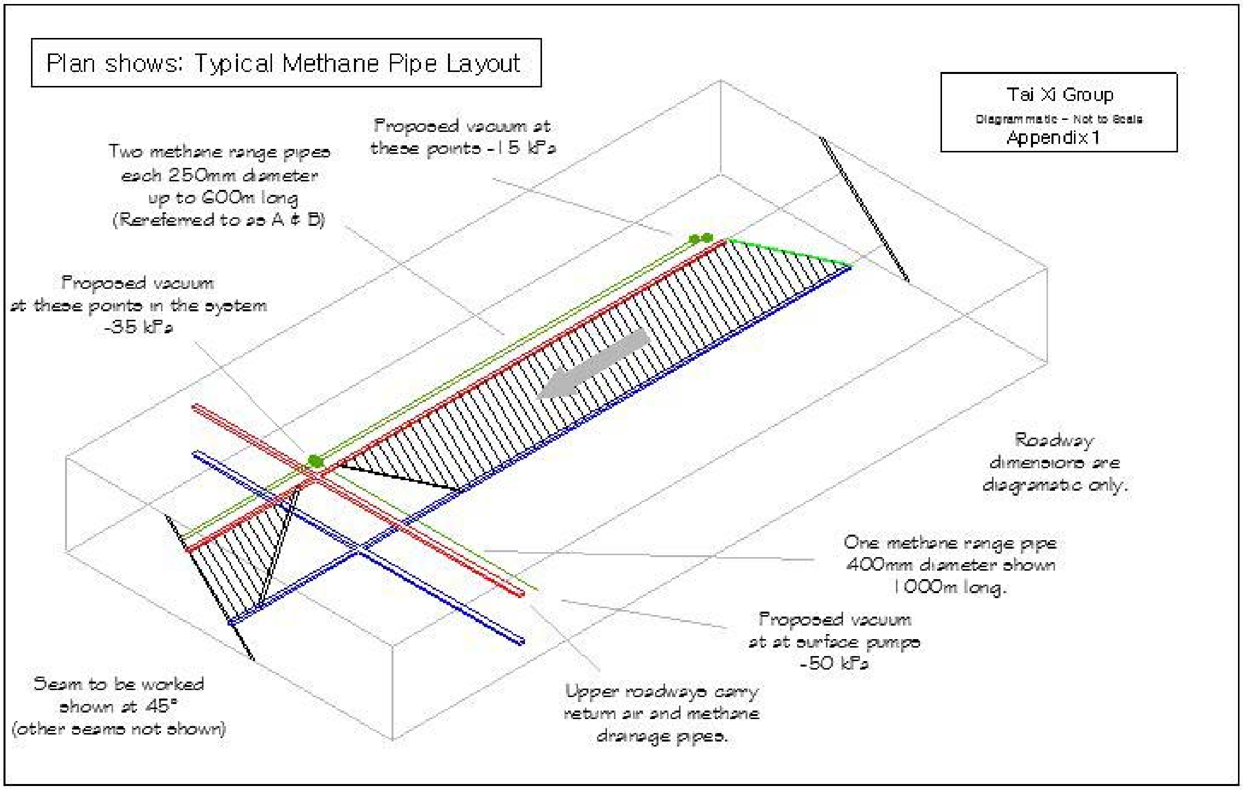

Figure 1.12: Methane Pipe Layout for a Typical Shortwall Panel

Based on findings of this report and an in-depth gas release analysis at the Song Shu Tan mine, a comprehensive gas-capture system for a hypothetical 300,000 mton/year Tai Xi Group mine is detailed in this report and will act as a template for the Tai Xi Group. As designed, it will enable Tai Xi Group to meet its target coal production goals and deliver sufficient gas to fuel an initial 10 to 20 MWe combined heat and power (CHP) project (see Section 4.0 for full discussion of CHP options).

2.0 METHANE CAPTURE AT TAI XI GROUP

All of the mines (except for the Xingtai #2) have chosen to mine the 2-1 upper seam first.[6] Historically, when the mines were autonomous, mining rates were low (i.e., typically 3,000 mtons per week). For example, anecdotal evidence from mine managers points to a few meters per week of retreat for the 70 m width shortwalls.

This low production rate might have been due to a number of factors, such as the inability to clear the coal from the shortwall or transport the coal from the mine in a modern and expedient manner. However, the most probable factor limiting the mining rate would have been the high gas emission rate from these seams, the lack of effective CH_4 drainage systems, and the low capacity of the ventilation fans observed at the Tai Xi Group. Indeed, during the April 2010 meeting at the Tai Xi Group, high gas levels were reported in the shortwall intake airways, return airways, and development headings at one of the mines starting production.

2.1 Current Methods Used to Capture Gas

The Song Shu Tan, Xing Tai, and the Ha Sha Tu mines are the only mines in the group currently developing a gas drainage system. Two of the low reserve mines have indicated that they do not wish to install a drainage system. However, based on the high gas content of the coal, all twelve of the mines must adopt comprehensive gas drainage if they are to achieve their production targets.

Three different CH_4 capture methods are being practiced and/or experimented with at the Tai Xi Group mines. These methods include:

- **Pre-drilled cross-measure drilling** has been carried out at the Song Shu Tan mine, where a whole shortwall series of 50-millimeter (mm) holes have been noted and angled at 34 degrees from horizontal over the soon to be mined shortwall at 2 m spacing. These were linked at six holes per 12 m-spaced manifold. The diameter of the pipe carrying gas to the surface was 150 mm. These pre-draining cross-measure holes at Song Shu Tan showed 100 percent pure methane at +1 kilopascal (kPa) closed borehole pressure (CBP), but no flow was apparent once the boreholes had been re-opened.

- **In-seam drilling** was observed at Xing Tai, where 25-mm diameter, in-seam holes were drilled in coal seam 7.2 and wells were spaced every 10 m. However, these have not been connected to a pump station.

- **Longhole drilling** undertaken by an Australian company at Ha Sha Tu Mine consisted of the drilling of nearly 8,000 m of hole in a total of 13 boreholes from four separate drilling stations. Each hole was typically 600 m long and 90 mm in diameter. Between 60 and 120 m of each hole was in coal. The seams penetrated include the 2-1 Upper, 2-1, 2-2, 2-3, and 2-4 (see Figure 1.1). The pipe carrying the gas to the surface was 100 mm in diameter. The longholes at Ha Sha Tu initially delivered 7 m^3/minute of flow at 100 percent CH_4 for brief periods, but this quickly died off to zero, and the CH_4 concentration was reduced to less than 15 percent, at which point the experiment was stopped.[7] The goal is to reduce the in-situ methane content by 30 percent.

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[6] According to the United Kingdom method of firedamp prediction, of all the seams, mining the 2-1 upper seam first will give the lowest total gas emission per mton mined.

[7] This effort was undertaken as a pilot program to test the effectiveness of this type of pre-mine drainage.

Based on performance to date, however, this goal does not appear achievable in the timescales presented to the mining engineers.

2.1.1 Current Effectiveness and Estimated Capture Efficiency

The pre-drilled cross-measure holes observed at Song Shu Tan mine will begin to work once the coal face has passed underneath them, causing the strata permeability to increase as the roof caves in. These holes will then begin to gather gas from above, as the coal seams become super-permeable due to this de-stressing mechanism.

Although pre-drilling holes is an easy and desirable method, shear stresses induced by the passing of a longwall face will invariably cut or crush most of the pre-drilled holes, bringing about reduced performance and wasted effort.

Although longhole pre-drainage efforts have been successful at several anthracite mines in Shanxi province, the experimental longhole drilling conducted previously by Tai Xi Group for pre-drainage at Ha Sha Tu has shown less than expected yields, most likely related to a relatively lower permeability to gas flow. During the mine visits to yet-to-be-started shortwalls, gas emissions were measured to be zero, indicating that no gas was permeating into the roadways from the exposed coal sides. This is another indicator that the coal is relatively impermeable.

Coal production is currently low throughout the Tai Xi Group mines (i.e., 40,000 mtons/week), primarily due to ongoing technical and safety improvements. Consequently, little to no strata disturbance was occurring and CH_4 liberation is minimal.

During normal shortwall production, the greatest gas emissions are expected to come from zones above and below the shortwall gobs due to roof caving and floor heaving. Gas emission from the mined coal seam itself is expected to be minimal by comparison, due to low permeability of the of the Tai Xi Group's coal. Measurements taken during the mine visit to the working shortwall at Xing Tai Mine #2 in seam 7.2 support this assumption. During the visit, the only gas of any significance measured by the study team was 0.35 percent in airflow of 8,330 liters per second (l/sec)—representing 29 l/sec. This was total release, as no drainage was in operation. At this time, the shortwall was retreating at 30 m per week and producing about 1,000 mton/week. This yields a 17.5 m^3/mton mined total gas emission rate, which is about the in-situ gas content of the mined coal.

At Ha Sha Tu, where longhole drilling has recently been carried out, mine personnel are expecting a 30 percent reduction in in-seam gas content. This means that 5.4 m^3/mton of CH_4 will have to be removed from the seam. Compared to the predicted 60 m^3/mton specific (total) release during mining, this would represent a 10 percent reduction in total emissions. Therefore, draining the worked seam (even if the coal is permeable) has only a partial effect on the total gas released, and the majority is contributed by other seams above and below the worked seam.

3.0 PROPOSED METHOD OF METHANE CAPTURE AT TAI XI GROUP

3.1 Analysis of Options

Many methods of CH_4 drainage exist around the world, such as:

- High-tech, in-seam guided holes drained using high-power surface vacuum equipment.
- Underground drilling.
- Simple pipes left in the gob, leading down to roadways to an area of low pressure within the mine airways, to draw gas away from the working area.

Table 3.1 summarizes possible drainage methods and indicates whether or not they are recommended for the Tai Xi Group mines.

Table 3.1: Methods of Methane Drainage

Method	Description	Recommended for Tai Xi
Hybrid cross-measure pre/post drilling (Third gate drilling)	Cross-measure holes are drilled from an adjacent in-seam roadway over or under the gob of the working longwall. They can be pre-drilled or post-drilled. The target angle is critical. Standpipes can be shorter if the strata are competent. The gas collector pipes run in this adjacent roadway. Pre-draining can occur but holes will produce most of their gas once the faceline has passed by. Pre-drilling will be more convenient; post-drilling may have a better capture efficiency. Experimentation will tell.	***Yes.*** Tai Xi would benefit from arranging the next shortwall's development roads to be driven early and drilling cross-measure holes from this adjacent roadway. They could be pre-drilled as a trial and post-drilled, comparing experiences and efficiency. Roof holes would be best drilled this way. Floor holes may be successful pre-drilled from shortwall return. If sequential mining occurs, floorholes from the adjacent roadway would actually be in-seam holes but would function as cross measures. Care must be taken passing under shear edge and slotted liners and/or post-drilling should be considered.
Drainage of old longwalls	When longwalls are finished, they continue to give off gas. It is important to seal these off from the ventilation air. Pipes can be left in the seals and connected to the drainage pipe network to carry on draining gas from the sealed off longwall. Sample pipes and flow measuring orifice sets should be included in the design.	***Yes.*** This will be particularly applicable to the Tai Xi Group if they work the seams sequentially downward (across horizontal intersect main roadway). Any gas in the gob of the lower longwalls will have a tendency to rise up into the gob of the higher ones. If these are sealed off and have a negative pressure created by the drainage system, additional gas can be removed by this passive inexpensive method.
Superjacent roadways with in-seam boreholes	Sacrificial roadway(s) driven in seam(s) underground—generally above and sometimes below worked seam. Shorthole in-seam holes then drilled as above. Gas pre-drained from these holes and also from seal put onto roadway. Longwall progresses, undermines roadway, coal becomes permeable, roadway and boreholes collect gas—much more gas migrating through seam.	***Possible.*** Can be effective but relatively expensive. In-seam drilling is an additional embellishment. Complicated task. Seal can leak, must take care with mine ventilation pressure distribution (gas safety). Main problem is that most of gas emits from floor. Because it is generally a roof-based system, some unknowns about floor drivages.

Table 3.1: Methods of Methane Drainage

Method	Description	Recommended for Tai Xi
Overlying roadways without boreholes	Sacrificial roadway(s) driven in seam(s) underground—generally above and sometimes below worked seam. Gas drained from the seal put onto roadway. Longwall progresses, undermines roadway, coal becomes permeable, roadway collects gas migrating through seam.	***Possible.*** Can be effective but relatively expensive. Seal can leak, must take care with mine ventilation pressure distribution (gas safety). Main problem is that most of gas emits from floor. Because it is generally a roof-based system, some unknowns about floor drivages.
Cross measure pre-drilling	Holes drilled from underground from the worked seam across the coal strata (i.e., coal measures). Drilled diagonally up over the longwall or diagonally down under the longwall before the longwall faceline has passed by. Standpipe inserted to make a seal in rock, vacuum applied—sometimes pre-drainage, or sometimes post drainage.	***Possible.*** No use for pre-drainage, but post drainage may succeed. Pipes are prone to shear stresses and can collapse, nip, or be broken, particularly in roof holes (gravity). Pre-drilling is easier than post-drilling. Often, trial and error will show if is successful. Pre-drilled holes will be more robust in floor and may be possible.
Cross measure post-drilling	Holes drilled diagonally up over the longwall or diagonally down under the longwall into target seams after the longwall faceline has passed by when the coal becomes super-permeable and transport paths open up. Roadway temporarily supported after faceline has passed, uses roadway center cloth ventilation arrangements. Standpipe inserted to make a seal in rock, collector pipes laid in roadway, vacuum applied, gas is captured.	***Possible.*** The system is cheap, effective, and gives decent capture efficiency and good gas concentration. Ideal for floor gas emissions (acts as pressure relief method too). Biggest problem is level of effort and expense required of supporting roadway behind the longwall faceline in the gob area. At Tai Xi's sloping seams, it would be very difficult to implement.
Pre-drainage coal bed methane (CBM) style from surface	Borrowed from the CBM industry. Holes drilled into coal from surface vertically, but can now be horizontal. Coal is generally permeable but is "fracked" with sand and high-pressure water to increase permeability. Water is pumped until hole dries out. Then gas is drained over a long period.	***No.*** The coal is not the desired permeability and fracking would need to be extensive. Gas would only come slowly. Drilling and fracking is expensive and terrain and climate are not favorable. Only targeted seams are de-gassed.
Surface gobwells	Holes drilled vertically from surface into area above longwall. Longwall retreats, gob collapses, the strata relieves, coal becomes permeable, gas rises up into gob and out to surface through borehole. Gas is typically collected from gobwells at 200 m spacing and led to vacuum plant some safe distance away.	***No.*** Most of the gas-producing seams are beneath the worked seam so gas would escape into gob and become diluted before being removed or would enter airstream. Drilling is expensive, surface pipes are exposed, terrain and climate are not favorable.

Table 3.1: Methods of Methane Drainage		
Method	**Description**	**Recommended for Tai Xi**
Long hole in-seam drilling	A few long holes drilled from underground within the mine are steered into the seam(s) of coal about to be mined or above/below coal about to be disturbed. Vacuum is applied and gas is drained over a period of months. Coal can be fracked if it's not at the desired permeability.	***No.*** The coal is not the desired permeability. Drilling is expensive and high-tech. Fracking is time-consuming and expensive. Only drains gas slowly from target seam. Post drainage in other seams—hole is at risk of collapse.
Short hole in-seam drilling	Many short holes drilled from underground on the longwall into the seam about to be mined. Gas is drained over a period of time before mining occurs. Can be fracked.	***No.*** The coal is not the desired permeability. Gas comes slowly and is prone to air in-leakage. Only drains gas from worked seam (good for outburst protection though).
Pack pipes	Pipes left in the gob. Just laid in horizontally and connected to drainage system or led to low-pressure airway.	***No.*** This method is very ineffective. Low capture efficiency, very low gas concentration. Can be dangerous if gas in pipes is 5 percent to 15 percent CH_4. Not recommended.
Sewer gates	Roadways are connected to the back of the longwall and a separate air circuit carries the gas-laden air backwards away from the working face, and it is diluted to safe levels further outbye in the mine. A zone of lower pressure is needed. Sometimes this gas is led to a surface fan altogether separate from the air circuit feeding the longwall.	***No.*** This would need much more airflow in the mine to create gas dilution circuits. Pressure gradients and multiple surface fan outlets can add complexity and much greater danger to the mining process.

3.2 Technical Analysis and Engineering Design for Selected Drainage Method Plan

Based on data obtained and measurements taken during the course of the pre-feasibility study, the study team recommends the Tai Xi Group consider adoption of the hybrid cross-measure CH_4 drainage for each shortwall throughout all 12 mines (see Table 3.1). The Tai Xi Group should also practice gob drainage from behind explosion-proof seals once the shortwall has finished producing.

The gas capture system recommended for the geology encountered in the Tai Xi Group will capture about 50 percent of the total gas emitted once the system is fully implemented. At full 4.5 million mtons/year production after 2020, depending on the sequence of mining, this will represent between 86 million and 154 million m^3 of pure methane captured per year, with a mid-point of 119 million m^3/year most likely to be captured. This level of methane capture is a realistic, achievable target. Mine management has a positive attitude toward the implementation of advanced techniques and technologies to improve safety and productivity.

While exact specifications for each small mine will be designed on a case-by-case basis, a general drainage method will be applied. This drainage method is based upon the principle that if a mine is taking coal from the seams sequentially downward, then capturing gas from the floor seams will always be paramount. These floor holes can be pre-drilled into the seams below the working coal face from the shortwall return roadway, or they can be pre- or post-drilled from an adjacent development roadway.

While the majority of the gas released should generally occur from the floor, if the coal is taken out of sequence or inferior seams are left in the roof, then drainage from these roof seams will also remain an important source of gas. Roof holes should be drilled from an adjacent roadway and can be pre- or post-drilled. Experimentation regarding whether to conduct pre- or post-mine drilling is the best way to determine the most appropriate choice.

Due to the steep seam geology at the Tai Xi Group, it would be difficult to temporarily support the roof in the return roadway after the faceline has passed by, so the roof holes could not easily be post-drilled. Post-drilling the roof holes from an adjacent development roadway is preferred. If the roof holes cannot be drilled from an adjacent development roadway, however, the remaining alternative would be to pre-drill from the return roadway. Experimentation with these drilling techniques might show which methods can avoid the worst of the shear stresses and get to the gas-bearing permeable zones within the target seam before shear stresses occur. Figure 3.0 shows the intense shearing forces that can potentially crush and shear boreholes drilled through this area.

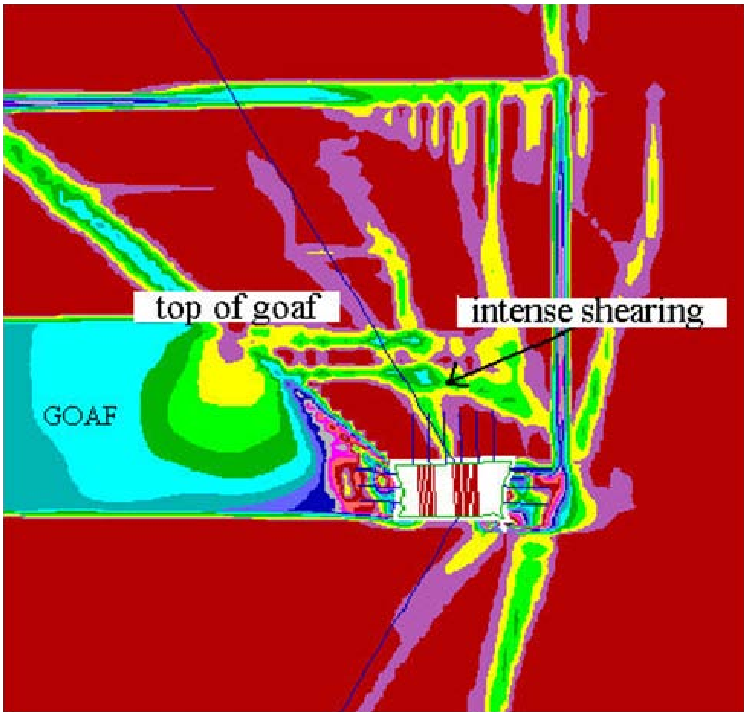

Figure 3.0: Rock Strata Stress Distribution Around a Longwall Coal Face

This drilling method from adjacent roadways might require changes in the Tai Xi Group’s mining development plans, as it will depend on the presence of an adjacent third gate roadway to facilitate the drilling of the holes (i.e., a roadway to form the intake roadway of the next shortwall. Preferably, holes from this roadway would be drilled after the longwall had passed.

After experimentation, however, it might be evident that shear stresses are local to the shortwall return roadway roof and holes leading from an adjacent gate might avoid the worst of the shear stresses and could be pre-drilled. In this case, the best of all scenarios—ability to pre-drill—would be achieved. Avoidance of shear stresses and ease of borehole management could be carried out quickly within the relative safety of the adjacent development roadway.

3.2.1 Mining Layouts

Tai Xi mining layouts will be designed to accommodate the steep seam geology found in their concession. Steeply-inclined seams typically present challenges requiring unique solutions, but at Tai Xi, the steep geology might offer an element of synergy regarding CH_4 drainage.

3.2.1.1 Shortwalls

Mining layout plans show a hybrid of horizon mining where the horizontal intake roadway is situated at the lower part of the seam and the horizontal return roadway is located at the upper part, yet they still sit apart at the full dip of the seam. The faceline would normally be 90 degrees to the intake and return sitting at full dip—which, in the Tai Xi seams, could represent a gradient as steep as 65 degrees from the horizontal. However, the Tai Xi Group has rather cleverly reduced the gradient of the faceline by angling it backwards away from the bottom roadway to a gradient that is 25 degrees from the horizontal (see Figure 3.1).

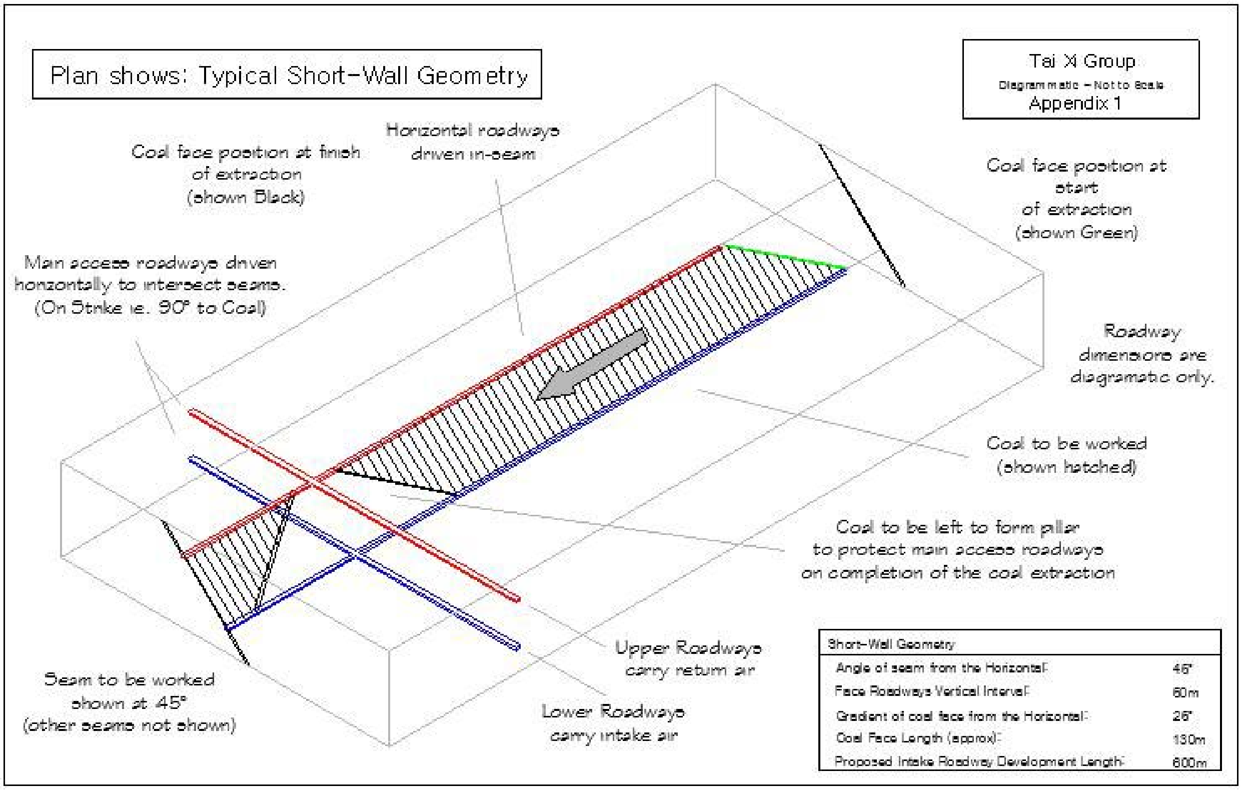

Figure 3.1: Shortwall Panel Layout for Tai Xi Group Mines

3.2.1.2 Mining Sequentially

The Tai Xi Group currently accesses seams sequentially, using horizontal roadways bisecting the line of full dip. This naturally leads toward a stepped-level method of extraction, where seams are extracted in sequence from these access roadways at a certain level. The next pair of access roadways is driven above or below the previous extraction, and the process is repeated.

In this stepped-level extraction method, the mine would access the coal-bearing strata at a certain level with a main return roadway and, typically some 50 m below (for a 45 degree seam dip), an intake coal handling roadway would be driven. Shortwalls would be taken off these main roadways, driving "gate roads" in the highest seam in the sequence that would extend to the edge of the mine boundary, to faults or to pre-designed stop points. The faceline would connect these two gate roads and retreat back (the faceline would mine back toward the main roadways). Once that seam had been mined, gate roads in the next seam down (horizontally along main roads) would be driven, and the process would be repeated until all of the coal in the coal sequence at that level had been mined (see Figure 3.2).

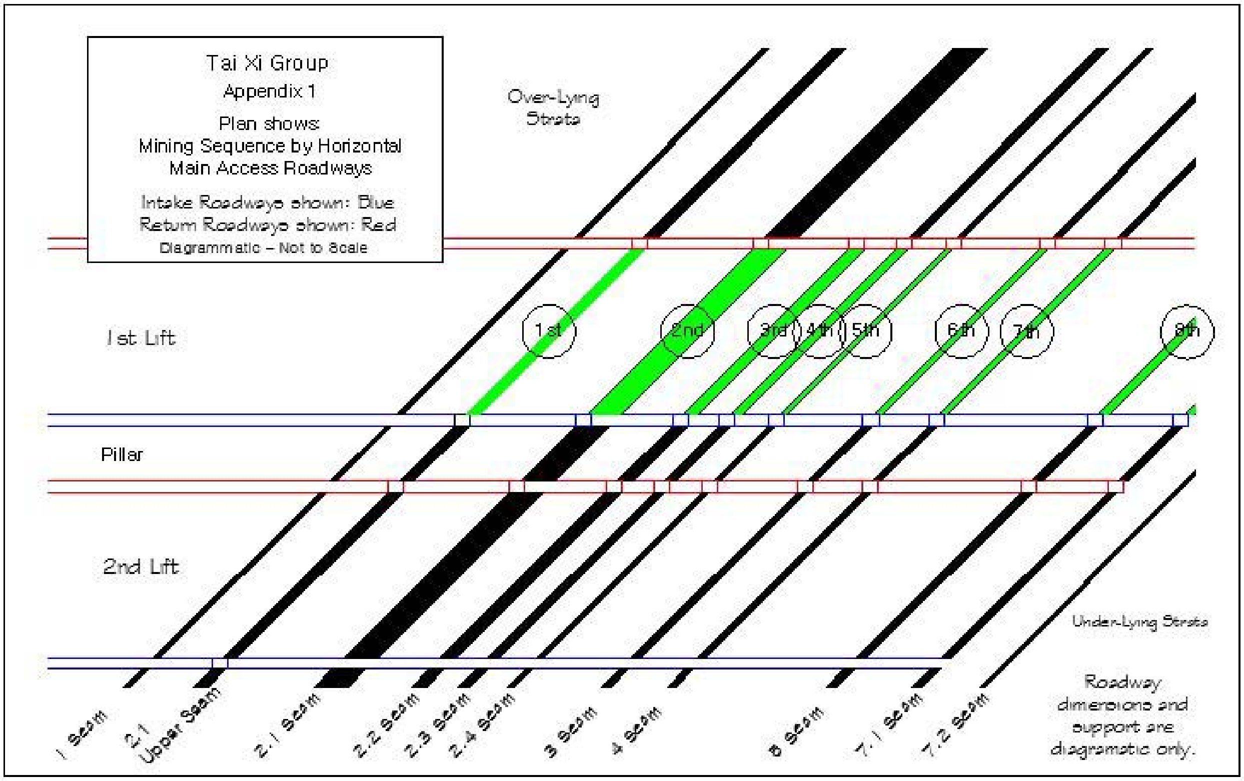

Figure 3.2: Mine Plan Where Seams are Mined in Sequence

If these seams are mined in sequence from these main roadways, they will find that the lower of the shortwall gate roads (the intake) will always be driven in de-stressed (more permeable) coal. This method might lead to problems with gas levels, and management must be aware that auxiliary ventilation airflow levels might need to be reviewed and increased commensurately. The upper gate road (the return) will be driven in virgin ground and should not endure undue gas emission while it is being driven.

If Tai Xi Group extract in sequence, top seam downwards, they will not typically need roofholes. These would only be needed for seam 2.1 upper (into seam 1 above) or if there are other inferior seams left above them not being mined in the sequence. In this case, these roofholes could be pre-drilled from the shortwall return roadway or, providing that the mine drives out the next seam's return roadway, they could be pre- or post-drilled from there. If mining is conducted such that lower seams are removed first, then roofholes will be required.

3.2.1.3 *Mining Seam-by-Seam Up-Dip*

Another method of mining is the more conventional seam-by-seam extraction most commonly practiced in less inclined coal-bearing strata. Here, for example, the 2.1 upper seam would be mined using a shortwall, and then another shortwall adjacent to it in the same seam would be developed and mined until the whole of the 2.1 upper seam was exhausted in that area. Then the mine would move down to the next seam (2.1) and repeat the process (see Figure 3.3). If the Tai Xi Group progressed with up-dip in this manner, they could then take advantage of the fact that the developments for the next longwall would create an ideal drilling site for "third gate drilling."

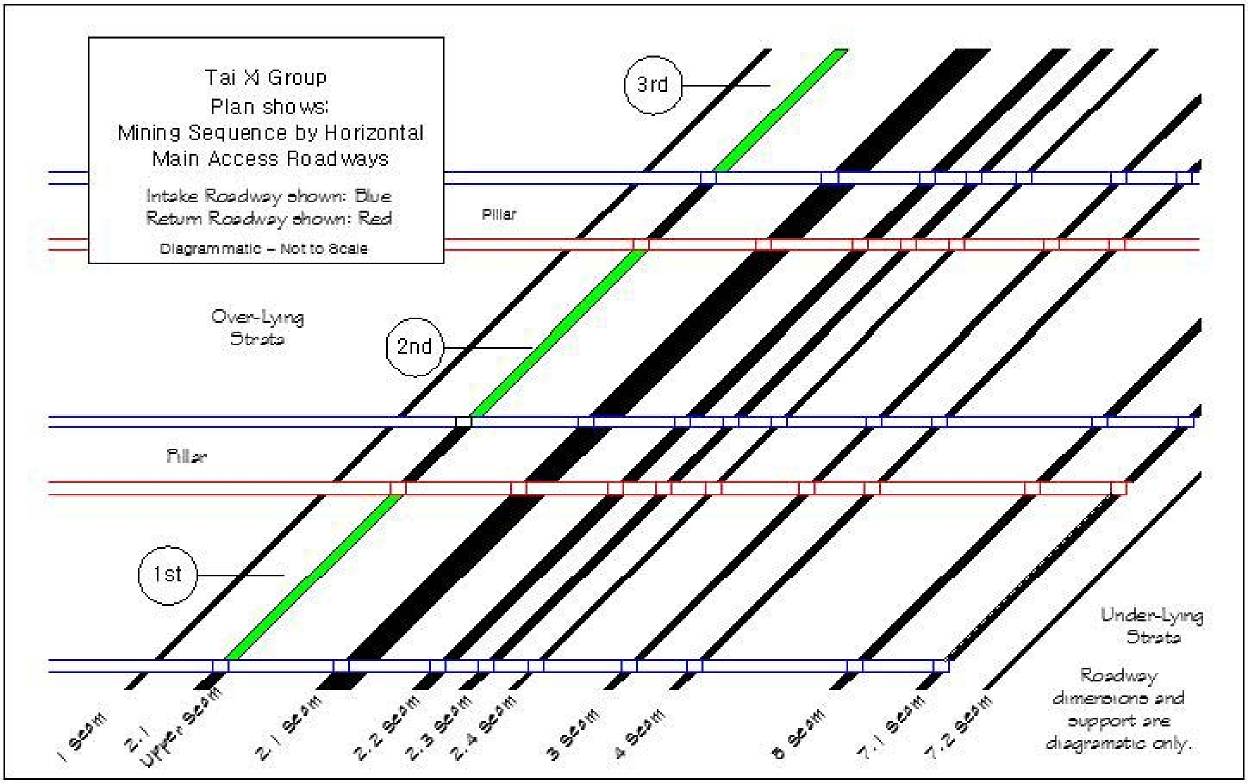

Figure 3.3: Up-Dip or Step Level Sequential Mining

Given the steep seam geology, accessing a particular seam to mine one shortwall and then having to prepare the main access roads repeatedly would be cumbersome; to avoid this, all of the horizontal access roadways would have to be driven in advance. This is an unwarranted expense and leaves roadways vulnerable to long-term degradation. Also, all the roadways would need ventilating when kept open, increasing demand on the ventilation systems. Discussions with mine management indicate that they will be mining sequentially one level at a time.

3.2.2 Methane Drainage System Design

3.2.2.1 *Drill Rigs*

To meet the drilling schedules necessary to achieve the productivity levels demanded by the Tai Xi Group, high-quality drilling equipment will be required. Specifically:

- Drilling should always be carried out with water flush (i.e., the holes should never be drilled dry).
- Water recovery, chipping separation, and then re-use should be integrated in the design. This will require the use of a hydraulic water pump.
- Rigs should be portable, robust, and electro-hydraulically powered. The mines might see financial benefits in purchasing track-mounted rigs from the outset. The rigs should be powered by a 25 kW motor, and the hydraulic pressures and flows should reflect this power.
- Drill bits should be polycrystalline diamond (PDC) or very high-quality Tungsten Carbide that can be sharpened regularly.
- Drill rods should be taper-thread, high-carbon steel with fused-on threaded ends at a manageable 750 mm long. Every tenth rod should be fitted with an internal, non-return valve to prevent undue water loss and sudden gas blow-back through the drill string.
- As soon as the standpipe is inserted and sealed in, the hole should be drilled through a "stuffing box" safety gland, which is a simple but effective and safe flow diverter. If gas under pressure is met, this device enables the hole to be connected to the CH_4 drainage pipe system while the drill rods and bit are being removed.
- Every drilling operation should be protected by a continuous CH_4 monitoring system to visibly and audibly alarm if extraneous gas is escaping.

Each shortwall will require its own drill rig (Figure 3.4). Mines producing 300,000 mtons/year are expected to operate two shortwalls at any one time. Mines producing 600,000 mtons/year will continually operate four shortwalls. Based on the Tai Xi mine conditions, in total, 30 drill rigs will be required for the 12 mines (30 shortwalls).

Figure 3.4: Example of Electro-Hydraulic Drilling Machine Used in the United Kingdom

3.2.2.2 *Roofhole Design*

Roofholes should be drilled to target and penetrate the next intact seam above the worked seam. When drilled from the return gate, standpipes are crucial to minimize leakage through broken ground and to reduce shearing effects. Using this technique, a standpipe should be inserted and sealed in with greased bandage (i.e., to provide a tight seal and prevent dirt and/or air from entering the pipe) up to either just below the target seam or 18 m, whichever is longer. Holes should be drilled at an angle designed to penetrate the seam where enhanced permeability and bed separation are occurring. As shown in Figure 3.5, the angle must be 55 degrees to penetrate the seam in a zone some 45 to 65 degrees extending up over the gob from the return gate road. The holes should be drilled 5 m apart. At the Tai Xi Group, in its return gate roads, these can only be pre-drilled and might offer limited success. An example showing roofholes drilled from the return in seam 2.1 upper to seam 1 indicates the holes will be about 12 m in length. At this length, the standpipe should be 10 m long, just leaving the seam exposed to the hole.

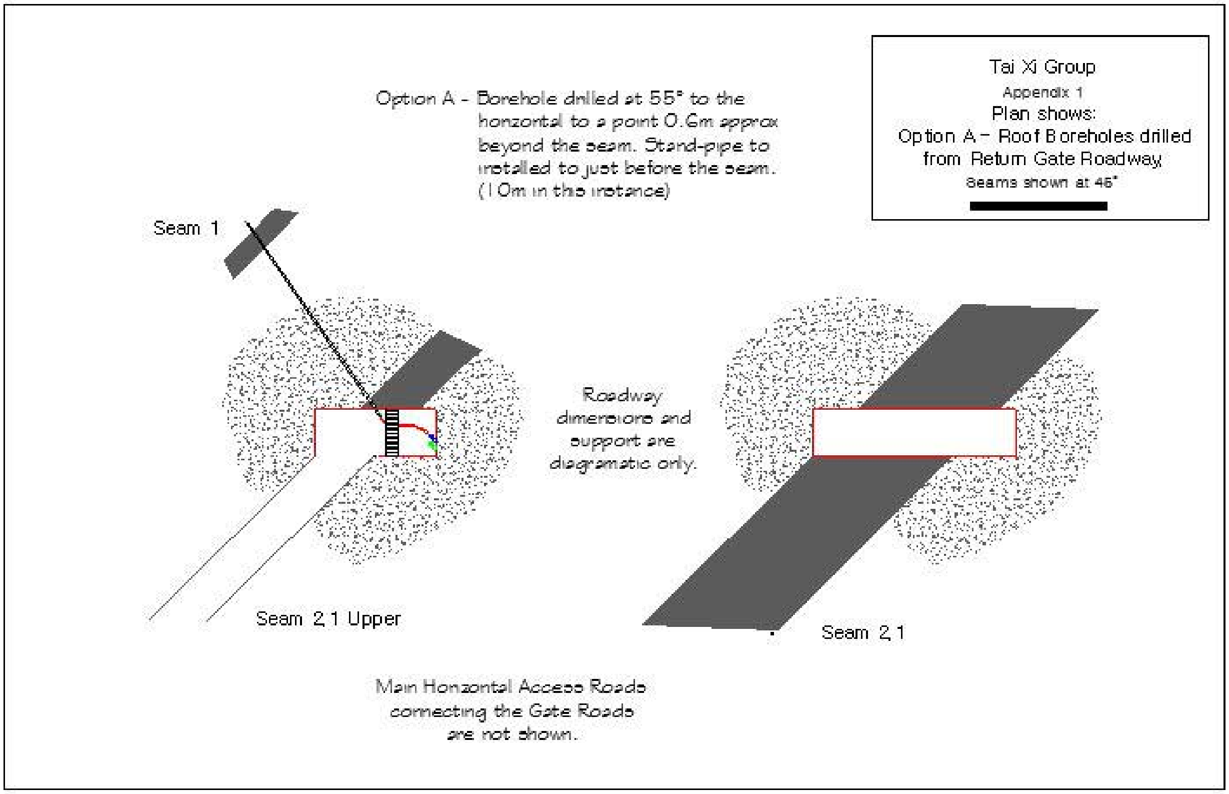

Figure 3.5: Drawing Showing Roofhole Design Drilled from Return Gate Road

In Figure 3.6, the angle is reduced to 15 degrees and the holes are 36 m long to achieve the same penetration point (for holes drilled from seam 2.1 through seam 2.1 upper and into seam 1). The holes should be drilled at 50 mm finished diameter, and the standpipe length can be minimized to 5 m, as the strata will be totally unfractured in this area. Again, it should be wide enough to accept a 52 mm internal diameter (id) standpipe able to be drilled through to complete the hole once it is inserted. The holes should be drilled 5 m apart. Drilled from a third gate, these holes can be pre- or post-drilled.

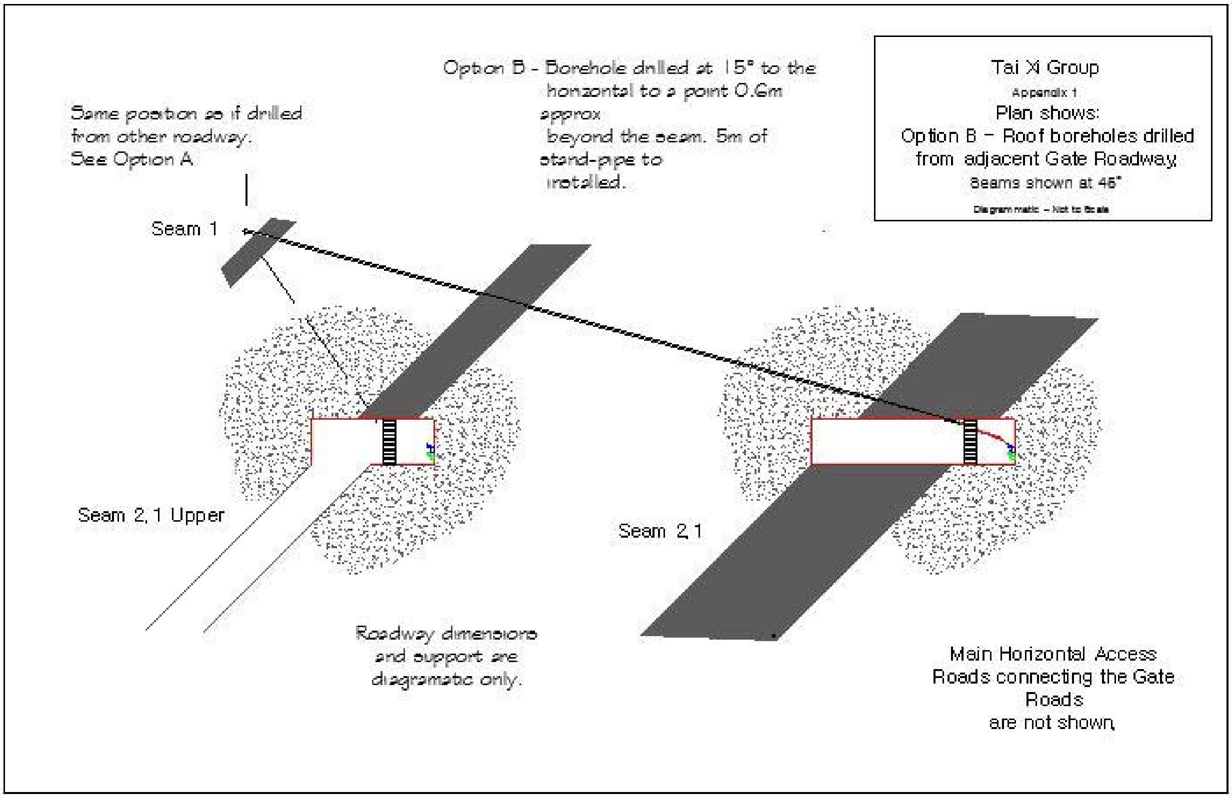

Figure 3.6: Drawing Showing Roofhole Design Drilled from a Third Gate

3.2.2.3 Floorhole Design

Floorholes should also be drilled to target and penetrate the next seam below the worked seam. A 5 m long, 52 mm id standpipe should be inserted, sealed,[8] and bonded to the strata with fast-setting resin. Fifty (50) mm holes should be drilled at an angle designed to penetrate the target seam where enhanced permeability and bed separation are occurring (in this case, 70 degrees to penetrate the seam extending below the gob from the return gate road). These holes should be drilled 5 m apart. Drilled from the return gate road, these holes can only be pre-drilled (see Figure 3.7).

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[8] It is important that the standpipes are sealed in properly, as gas from the floor seams can be trapped for many days after disturbance by mining and then released with considerable force.

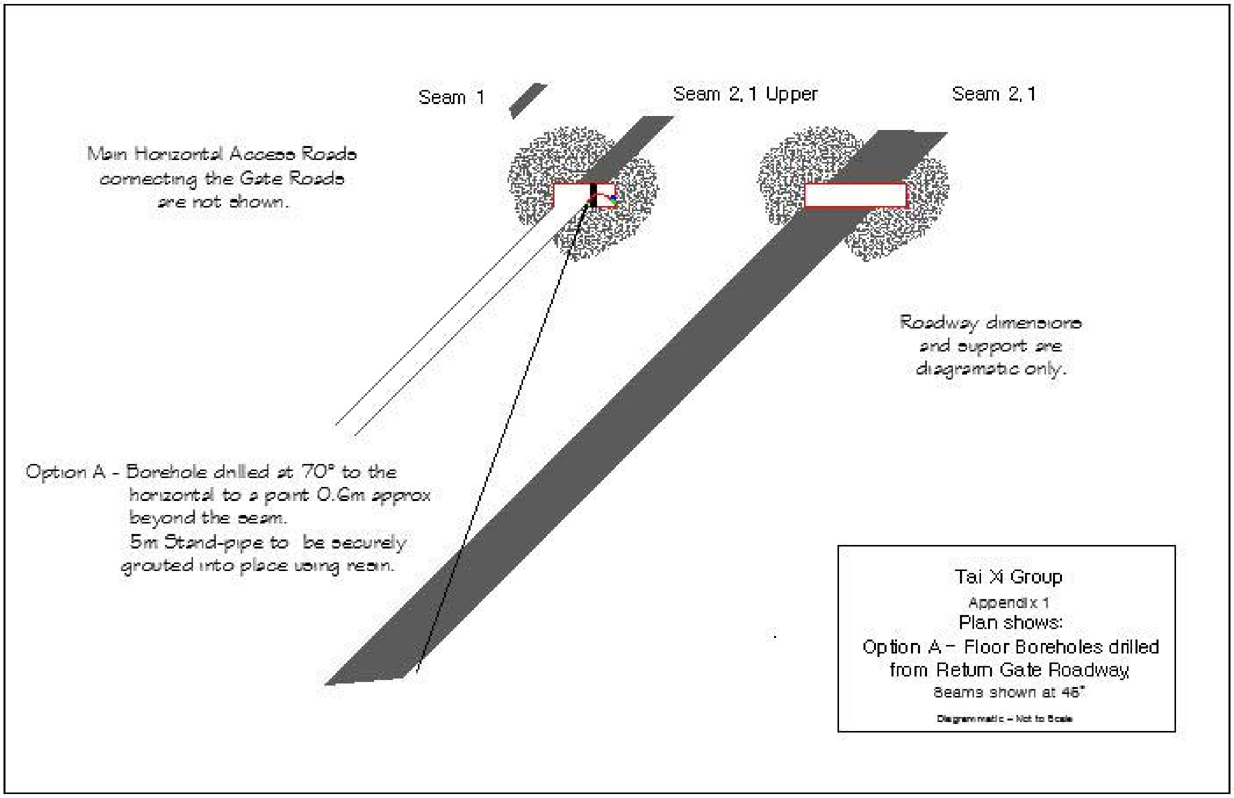

Figure 3.7: Drawing Showing Floorhole Design Drilled from Return Gate Road

In Figure 3.8, the angle is reduced to 45 degrees to achieve the same penetration point (i.e., the same gradient as the seam full-dip angle). In this case (drilling purely in coal), the standpipe should still be 5 m long but of a greater diameter at 76 mm id. The hole should then be drilled inside this standpipe and able to accept a slotted liner at 52 mm id.[9] Again, these holes should be spaced 5 m apart. From a third gate, these holes can be pre- or post-drilled.

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[9] Because the hole is drilled in coal, if it was not protected by the slotted liner, it would be liable to collapse from faceline pressure stresses as it sits under the gob.

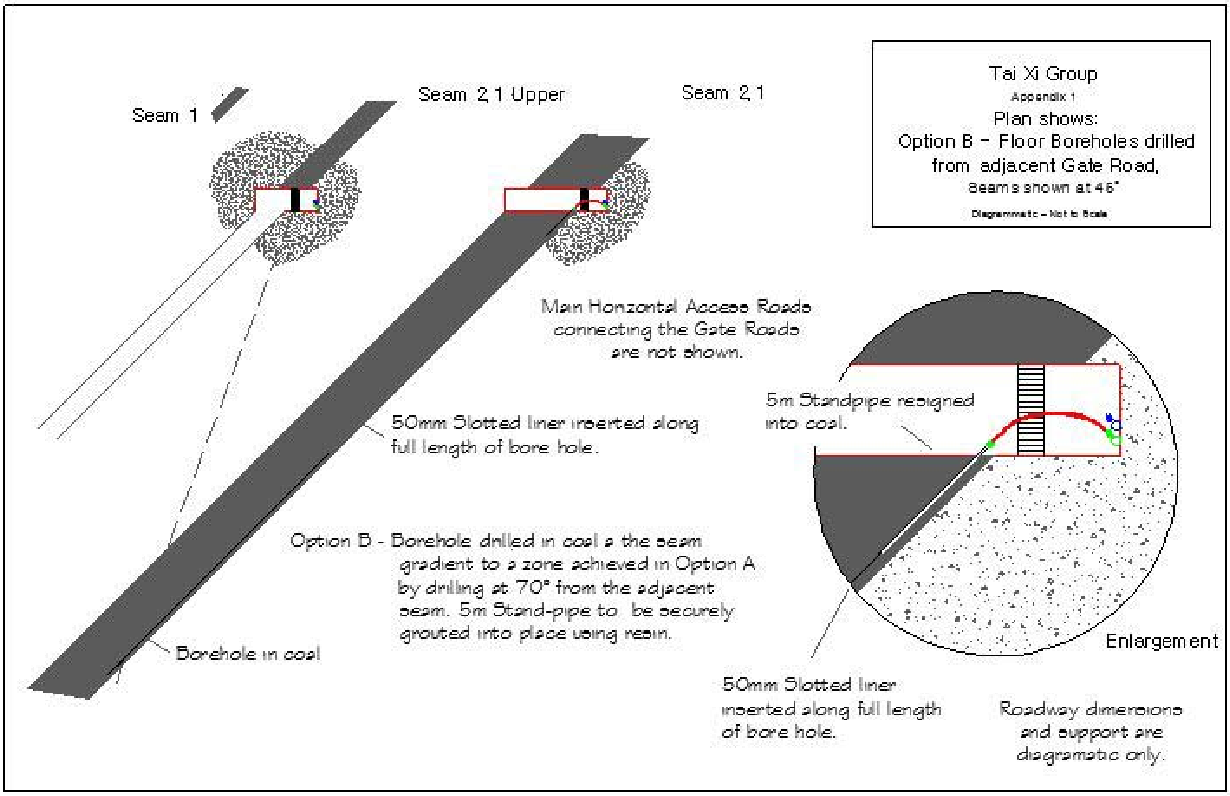

Figure 3.8: Drawing Showing Floorhole Design Drilled from Third Gate Development Road

3.2.2.4 Shortwall Seal Design

If the mine extracts coal sequentially, the worked-out longwall (gob) will act as an overlying roadway. Although not gathering gas from the mined seam (i.e., the gas has already been extracted), there will be some overlap where additional fresh coal is disturbed. The worked-out longwall will act as a perfect conduit for any gas emitted from this seam.

Finished shortwalls should be properly sealed to minimize gas leakage outward and air leakage inward. It is suggested the seals be constructed of two brick walls keyed into the surrounding rock and the space between these walls filled with dense cementitious grout (rather than foamed material).[10]

Pipes should be put through the seal and fitted with valves and orifice flow-measuring sections. The first drainage pipe should be 150 mm and lead to free air space in the roof 20 m behind the seal. The second pipe should be 150 mm and lead to the two old gate road drainage pipes, which should still be connected to the methane drainage boreholes. The third pipe should be a 10 mm sample tube, leading to the roof about 20 m behind the seal.

Care should be taken to ensure that the seal is at a lower pressure in the main roadway than that of the working shortwall. See Figure 3.9 for a drawing of a shortwall seal.

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[10] This helps minimize leakage, but also adds mass in the event of an explosion behind the seal. If the spacing between the walls in meters follows the formula for roadways of (Height(m) + Width(m) / 2) + 0.6 m, or is a minimum of 3 m long (whichever is the greater figure) then in the United Kingdom, the seal is deemed explosion proof.

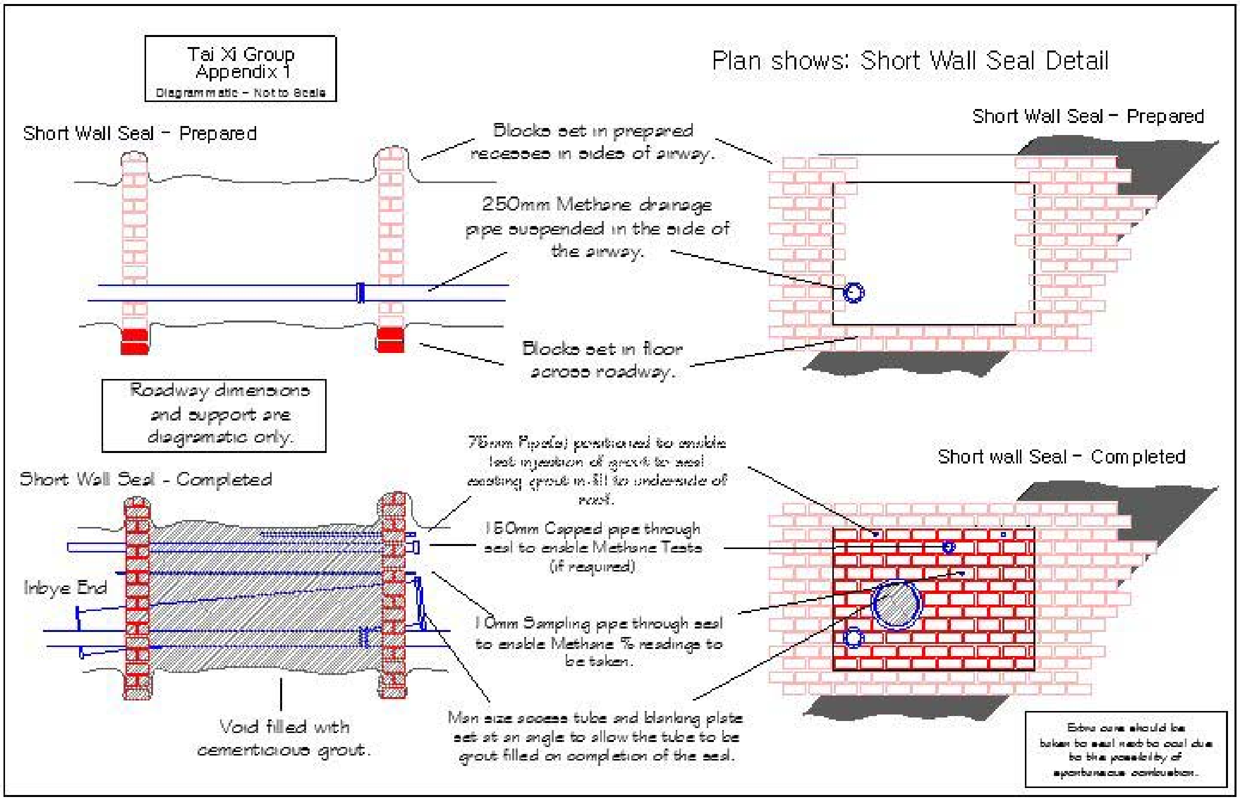

Figure 3.9: Drawing of a Shortwall Seal

3.2.3 Drainage Pipe Network Specification and Design

Once any borehole is completed, it should immediately be connected to the pipework system using flexible hoses and an orifice flow-measuring section. Fifty (50)-mm valves should be fitted to the wellhead and the point where the flexible hose meets the drainage pipe (see Figure 3.10).

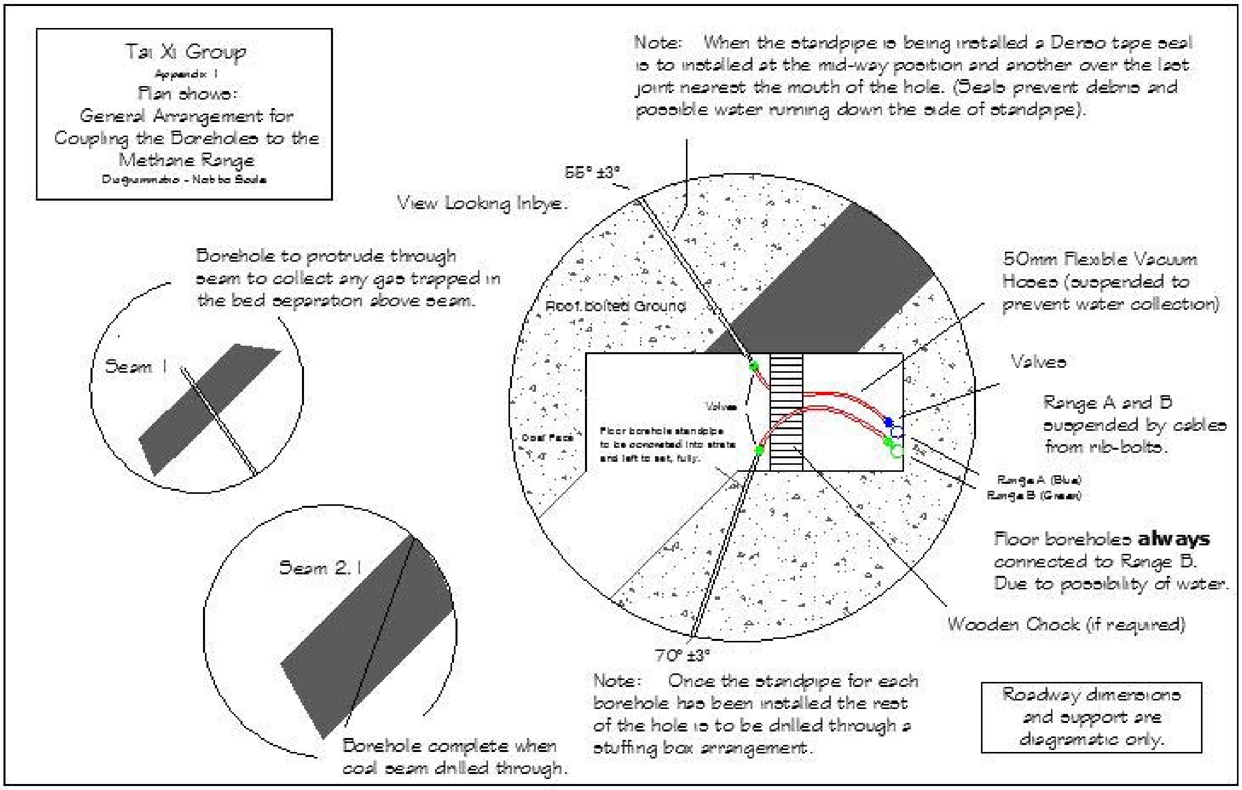

Figure 3.10: Drawing Showing General Arrangements for Coupling a Borehole to the Methane Drainage Pipe

Provisions should be made to drain water from the pipework (see Figure 3.11), and at least two separate pipes should be led along the roadway to allow alternate batch coupling to regulate the suction applied to the boreholes. Notably, the present diameters of the CH_4 drainage pipes at the sites are inadequate to carry away the quantities of gas for the proposed mining rates and still achieve a correctly engineered suction at the boreholes. The two pipes running along the shortwall return gate road (for standard cross-measure drainage) should each be 250 mm internal diameter and made of steel.[11] The pipes should be laid in the top corner of the roadway and preferably sandbagged or otherwise covered to avoid any strata collapse after the faceline passes.

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[11] As previously mentioned, the use of PVC is considered dangerous and should not be used for CH_4.

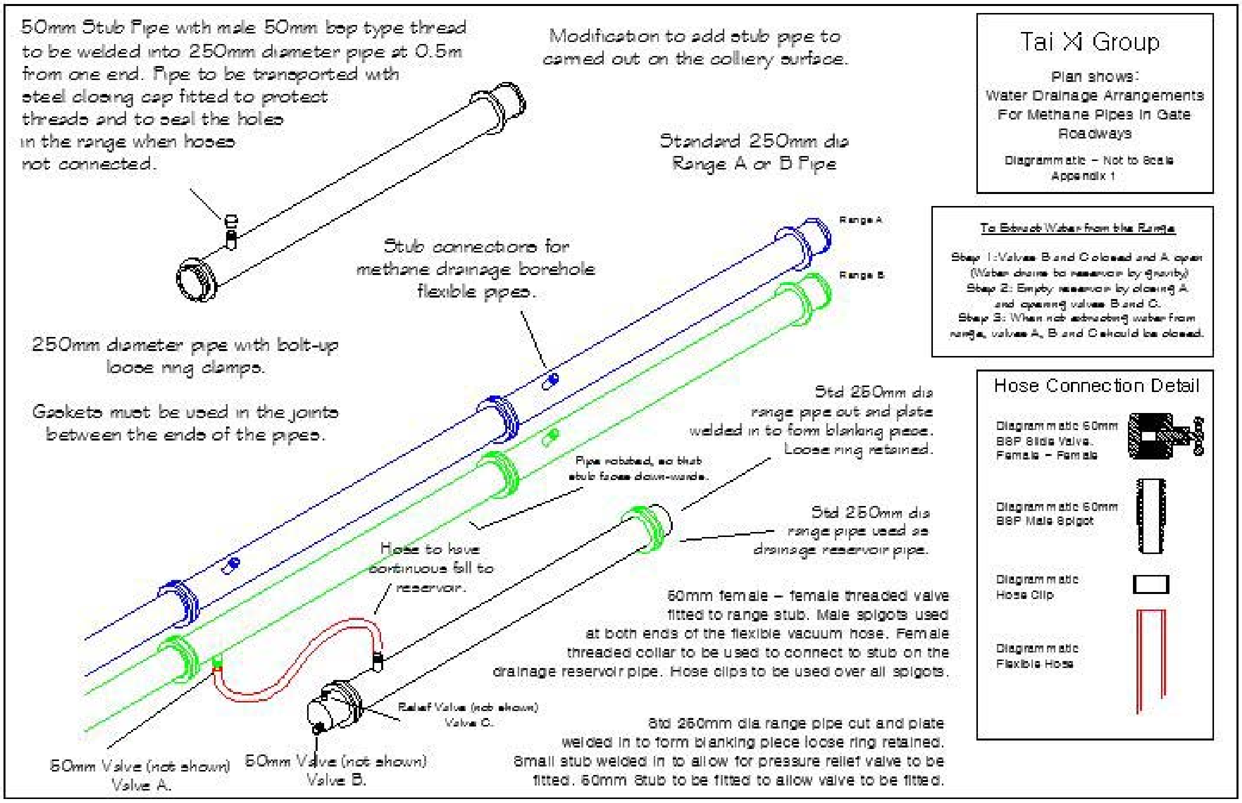

Figure 3.11: Drawing Showing Water Drainage Arrangement from Methane Drainage Pipework

In the third gate drainage scenario, steel pipes should also be duplicated and again, the two pipes should be 250 mm internal diameter. The pipe leading along the main access roadways to the drift bottom should be 400 mm in diameter, as should the pipe leading out of the mine and up the drift.

The following is an example of how a mine at the Tai Xi Group should be laid out: 1,000 m of 400 mm diameter pipe plus a branch of two 250 mm steel pipes leading up a shortwall approximately 600 m long (with only one of the pairs working) should be able to carry a “worst case” 1,300 l/sec mix off each shortwall to total a 2,600 l/sec mix leading to the surface. This flow would give a total pressure loss of 35 kPa when the surface pressure was 50 kPa of vacuum (the design pressure of the pumps). This means there would be 15 kPa at the base of the cross-measure boreholes in the mine (i.e., ideal design pressure) (see Figure 1.12 on page 20).

As pipes are installed, they should be pressure tested for leaks, and every effort should be made to avoid drawing air into the pipe system. Isolation/regulation valves should be installed at strategic sites, and orifice flow-measuring sections should be installed at pipe branching locations in order to identify piping sections that may be leaking.

3.2.4 Methane Extraction Plant Specification and Design

Tai Xi Group engineers determined that three CH_4 utilization plants should be constructed at the mines, and based on the outcomes of this feasibility study, the study team concurs with this recommendation. Potential sites include the:

- Song Shu Tan main drift in the southern part of the mining area.
- Xing Tai main drift in the center of the mining area.
- Bei Li Gou deputy drift in the northern part of the mining area.

Assuming production would be split equally among the three plants (i.e., 1.5 million mtons/year), each plant should be capable of handling equal amounts of gas.

The study team estimated a minimum gas flow scenario for plant sizing. The scenario is as follows:

- Estimated upwards of 307 million m^3 of pure methane per year in a total mixture flow of 1,228 million m^3 at 25 percent CH_4 coming out of Tai Xi Group mines.
- Each of the three plants should be designed to carry 409 million m^3 of mixture per year. Assuming 100 percent operation, this means that each plant must be able to handle a mixture flow of 46,727 m^3/hour, or 779 m^3/minute. This mixture flow of the gas must be handled even when the pumps are drawing down to a vacuum of 50 kPa, the working design pressure at the surface.
- Installations must have minimum standby capacity.
- 2,000 kWe of pumping power will be required at each of the three plants.
- Each plant has four 500 kW pumps. These can each carry 300 m^3/minute of mine gas. These should be liquid ring pumps, which offer long-term reliability, fundamental safety benefits, and simple technology that is widely available from domestic manufacturers.
- The pumps should preferably be frequency-controlled (i.e., for less damaging soft-starts) and also provide variations on duty in between the 1-, 2-, or 3-pump operation. The fourth pump should be kept as a standby and/or as a peak capacity plant.
- The pumps will be installed in parallel in between inlet and outlet manifolds.

All pipework within the CH_4 plant buildings should be installed at a high level to avoid water carryover. As well as using gravity, water drop-out tanks should be installed on the outlet of each pump and the captured water should be recycled back to the reservoir. Also, in between the inlet and outlet manifolds, two connection circuits should be introduced, one incorporating a recirculation valve and the other a pressure relief valve. The recirculation circuit is used to fine-tune the flow rate between the pumps. The pressure-relief circuit is provided in case the inlet or an outlet manifold of the pumps becomes blocked (Figure 3.12).

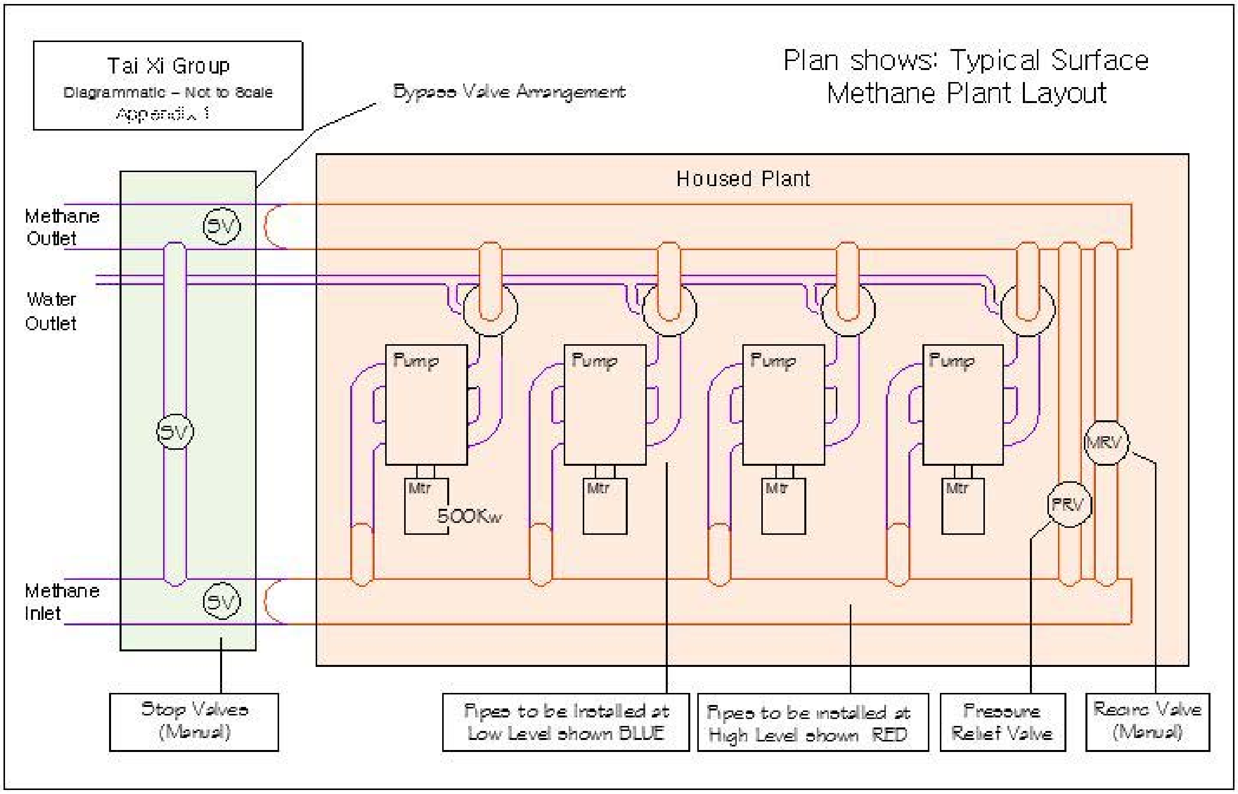

Figure 3.12: Schematic Drawing of Typical Methane Plant Layout

The entire plant should be capable of being isolated from the outside as a failsafe measure in the event of a plant shutdown or emergency, and the gas from the mine should be capable of being directed to the vent stack or “free vent” (i.e., bypassing the methane plant altogether).

When the plant is in normal operation, the stack should be fitted with a roll-out valve (e.g., diaphragm pressure control valve) to allow gas to safely vent once a set pressure in the discharge pipeline has been achieved. This ensures the vacuum pumps have the correct backpressure to prevent undue water carryover, and that gas to be utilized is at the correct pressure for the gensets.

The CH_4 extraction plants should be fitted with orifice flow-measuring sections and should also be able to measure pressure and methane concentration. These should be electronically measured and recorded hourly.

3.3 Effectiveness and Predicted Capture Efficiency

Total CH_4 capture efficiencies from this hybrid cross-measure method are expected to be 40 to 50 percent once the drilling teams are proficient. When production begins in 2011, the Tai Xi Group will begin draining CMM in proportion to the mining rate.

The mining method is identical throughout the Tai Xi Group; therefore, the drainage method will be a similar process throughout, with details adjusted to suit the local geology of each shortwall. Drained gas is expected to be of consistent quality and quantity from each shortwall and each mine. The drainage system will be designed to deliver 25 to 30 percent CH_4 concentration at the surface. In time, the gas drained through cross measures might be supplemented by gas drained from the gob behind the seals.

At full production, the Tai Xi Group will be retreating about 30 shortwalls. The shortwalls are all planned to be approximately 70 m wide and between 300 and 600 m long. The faces will be worked by drill and blast, where small explosive charges are used to remove the coal from the coalface. The very nature of the steeply inclined seams will cause the coal that is removed from the face to tumble down the coalface into the hopper/feed system and then into the coal transportation tubs. Once the tubs are loaded (by gravity) they will either be removed with a winch from the mine or a conveyor system will transport the coal up the drifts to the surface.

At full production, it is estimated that there will be between 171 million and 307 million m^3/year of pure CH_4 released by mining (average of 239 million m^3/year). This number will depend on the degree of previous mining in each area.

3.3.1 Manpower

Based on the study team's experience, operating a successful methane drainage system at each mine requires the following manpower:[12]

- Four teams of three drillers
- Two technicians
- One supervisor

A total of 15 men per 300,000 mtons/year of coal production are required (four teams of three drillers, two technicians, and one supervisor), and mines that produce 600,000 mtons/year will require 30 men; hence, a total of 225 men will be required for the full coal production level of 4.5 million mtons/year.

Personnel training should consist of, at a minimum, approximately one week each of surface training and underground training. Typically, five men per week could be training underground. Twenty men could be trained on the surface per week. Alternatively, a buddy system could quickly be established underground, so multiple teams could be trained as quickly as in the classroom and workshop once a critical mass of trained workers has been established.

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[12] Assumes each mine produces 300,000 mtons/year.

4.0 METHANE UTILIZATION RECOMMENDATIONS AT THE TAI XI GROUP

Many CMM utilization methods (i.e., end uses) exist around the world. These methods range from high-tech chemical conversion technologies to power generation in reciprocating gensets, to gas turbines or combustion in simple boilers or abatement through flaring. The most suitable end use for CMM also depends on a number of factors including technical feasibility, cost effectiveness, gas quality, and local energy market demands and needs.

4.1 Analysis of Utilization Options

Table 4.0 summarizes the possible CMM utilization methods and indicates whether or not they are recommended.

Table 4.0: Suitability of Various Coal Mine Methane Utilization Options for Tai Xi Group

Method	Description	Suitability for Tai Xi
Liquifaction to liquefied natural gas (LNG)	Remove essentially all nitrogen and CO_2 and maintain hydrocarbons in liquid state for shipping	Not suitable due to high expense and remote location
Enrichment to pipeline quality in gaseous state	Remove essentially all nitrogen and CO_2 and build pipeline to main pipeline transmission system	Not suitable due to high expense and remote location
Vehicle fuel – gaseous state	Compressed natural gas (CNG)	Not suitable. Evidenced low and variable hydrocarbon content makes this a poor vehicle fuel.
CMM-fueled combined cycle turbine gensets	Not tolerant of variable CH_4 concentrations and low efficiency at high altitudes	Not suitable because of high elevation of mines and requires inlet compression
CMM-fueled reciprocating engine gensets with CHP	Proven technology for CMM's variable CH_4 content	Suitable for application
CMM-fueled reciprocating engine gensets without CHP	Proven conventional technology for CMM	Suitable if there is no use for waste heat recovery
Use in industrial applications such as boilers or furnaces	Proven technology for CMM application	Suitable. Reduced coal combustion for power generation in the existing thermal power plant would be achieved if end-use CMM co-fire burners are installed.
Use on colliery site or for water or steam	For mineworkers bathhouses	Suitable application
Use onsite for slurry drying		Suitable if needed
Domestic distribution in raw state	Cooking and heating	Suitable if quality can be maintained
Flaring	Simple CH_4 destruction	Suitable for excess gas not usable in established utilization equipment

4.2 Recommendations for Onsite Utilization Technologies at the Tai Xi Group Mines

The study team evaluated two onsite utilization options for consideration at the Tai Xi Group mines:

- Combined heat and power utilization
- Ventilation air methane destruction and utilization technology.

4.2.1 Combined Heat and Power Utilization Project

Based on the analysis of the data and other evaluation factors considered throughout this report, a CHP project is recommended and should be considered as the preferred utilization option.

By the end of 2011, the proposed gas drainage system is expected to be largely operational at most mines (depending on their level of development) and capable of achieving at least 30 percent CH_4 capture efficiency. The gas drainage system will drain 24 million m^3/year of CH_4 from the group of 12 mines. The CHP equipment should be installed in increments of 5 MWe each after the initial 15 MWe installation in 2012, based on the schedule outlined below and forecasted methane drainage rate in Figure 4.0.

- Phase 1: Initial installation of 15 MWe CHP equipment by 2012.
- Phase 2: Additional 5 MWe by 2014.
- Phase 3: Additional 5 MWe by 2016.
- Phase 4: Additional 5 MWe in, or around, 2018.
- Phase 5: Additional 5 MWe in, or around, 2020 for total CHP equipment installation of 35 MWe over 10 years.

The CHP equipment should be installed in increments of 5 MWe each after the initial 15 MWe phase, based on the forecasted methane drainage rate in Figure 4.0. In Phases 1 and 2 (2012 to 2014), the 20 MWe of CHP should be split between the three CH_4 drainage plants depending on the expected mining rates at each site. Once the gensets are commissioned, the CHP heat recovery equipment should be linked to an insulated hot water distribution network feeding heat to the relevant mines' intake drifts. Heat exchange equipment should be constructed and commissioned at the intake air drifts concurrently with the CHP genset plant and the hot water network.

By 2013, the amount of pure CH_4 gas being drained will have increased to 38 million m^3/year or equal to at least 40 percent of all of the released gas). If coal recovery and gas drainage targets are met by 2015, Phase 3 of the proposed methane utilization project should be constructed for use in 2016. The remaining phases are expected to be implemented based on actual coal and gas production. Where the available usable gas exceeds the installed capacity, any excess gas should be flared to reduce GHG emissions.

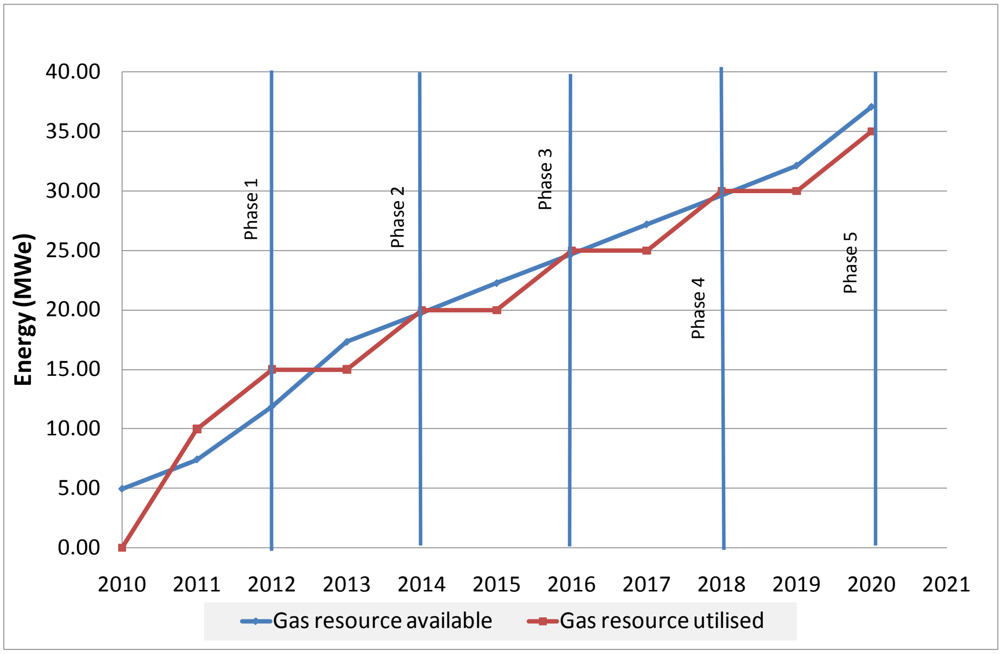

Figure 4.0: Expected Timing of the Installation of Power Generation in Phases as Coal Mining and Gas Production Increases

4.2.2 Ventilation Air Methane Destruction and Utilization

Historical VAM concentrations related to the previously-independent small-scale mining are not considered relevant to the modern layouts and ventilation machinery planned by the Tai Xi Group. Using the current mine plan, the Erdoaling sequence of seams, and knowledge of gas contents, the study team predicted future gas emissions and calculated ventilation air flow required to dilute these emissions to 18 m^3/s at each shortwall. See Table A-3 in the appendix for the predicted gas release into mine ventilation air and required airflow levels.

Modeling the Tai Xi Group mine ventilation systems highlights the large quantities of additional airflow that will be required to support the auxiliary ventilation of roadway developments necessary for shortwall mining systems. For this reason, even though the shortwall return roadways have a design level of 1.0 percent CH_4, the large dilution factor brought about by auxiliary ventilation feeds and typical air leakages within the mines (i.e., 300,000 mton/year units) predicts VAM concentrations at the surface fan evasé will be between 0.2 and 0.4 percent CH_4 (calculated at 0.36 percent).

The commercial benefit of VAM destruction comes almost exclusively from Certified Emission Reductions (CERs). Although it is technically feasible to oxidize ventilation air with CH_4 concentrations as low as 0.2 percent, the current capital costs of VAM abatement equipment are so high that even with incomes from CERs, projects below 0.5 percent will fail to show adequate internal rate of returns (IRRs). Therefore, unless the following parameters emerge, the VAM destruction scenario does not appear to be a viable alternative for the Tai Xi Group mine:

- Installed costs are reduced significantly
- VAM concentration is found to be consistently above 0.5 percent
- Value of CERs significantly increases

Electrical generation from heat produced during the VAM oxidation process is technically proven; however, the economics require VAM concentrations higher than those expected at the Tai Xi Group, and the CAPEX is so high that risks or uncertainties must be minimized. Gas emission data based on predictions alone is not considered a solid enough platform from which to launch such technology. Therefore, VAM abatement at the Tai Xi Group is not a recommended option at this stage. Once full production is being achieved and real-time data is obtained, this issue can be revisited.

4.3 Combined Heat and Power Utilization Project Overview

The Tai Xi Group mines are predicted to be operating at full capacity by the end of 2020, at which point they will become dependent on imported electricity. To augment the security of its energy supply, study team recommends the Tai Xi Group install up to 20 MWe of CMM-fueled generating capacity by the end of 2013. This capacity would consume approximately 37 million m^3 of pure methane per year; this power generation capacity is sized to the average gas resource forecast for the mines, and is thus considered conservative.

To further reduce carbon emissions and improve the thermal efficiency of the proposed project, the gensets should be fitted with heat recovery steam boilers (HRSG) to capture exhaust gas heat and provide hot water for ventilation air pre-heating in winter. These CHP gensets must be packaged for the cold climate.

At the Tai Xi Group, this CMM end use, at 20 MWe and 17.7 MWth, will achieve several important benefits, including the following:

- Recovery and utilization of CH_4 will reduce annual CO_2 emissions by approximately 576,000 mtons CO_2 equivalent.
- Using CMM to generate power for ventilation and methane pumping will help the Tai Xi Group mines meet their growing electricity requirements. When they reach full production, the mines and their general location are expected to demand at least 22.6 MWe.
- Using CMM for electricity generation will also help the mines achieve energy supply security. The mines are currently limited in their ability to import electricity (a maximum of 7 MWe) from the national power grid.
- Using waste heat recovery will enable the mines to save more than 10,000 mtons of coal combustion for mine air heating during six sub-zero temperature months of the year.

The projected increases in electrical demand will be, in part, a result of the mines' increased ventilation and CH_4 drainage requirements as coal production increases to 4.5 million mtons/year by 2020. Increases in ventilation requirements also give rise to commensurate increases in electricity consumption and shaft heating heat requirements. These additional power and heating requirements would normally be fed by increased coal combustion. However, if the drained CMM resource is utilized for power generation, it is likely that little or no additional coal combustion will be required over present levels. (See Section 6.0 for the full CMM utilization economic analysis.)

4.3.1 Safety Considerations of Combined Heat and Power Project Genset Choice

Recommendations for the safe operation of CMM-fueled gensets at the Tai Xi Group mines include the following:

- If Tai Xi Group selects high-efficiency gensets (typically manufactured in Europe or the United States), it should be noted their fuel carburetion systems are designed to be incapable of consuming a fuel gas with less than 25 percent CH_4 concentration in air. Therefore, the CH_4 concentration of the CMM fuel gas will always significantly exceed the upper explosive limit of 15 percent CH_4. This means that whenever these gensets are in operation, the risk of explosion of CMM will be significantly reduced.
- If Tai Xi Group selects domestic gensets, it is essential that control systems currently deployed (i.e., allow low-concentration gas to be utilized) should not be specified in the scope of supply and prohibited from retrofitting. The gensets' internal combustion engines and control systems must rely on conventional carburetion and consume CMM at gas concentrations greater than 25 percent CH_4 in the same manner as Western gensets in order to reduce the risk of CMM explosion to a level equal to that of Western genset use.

4.3.2 Specification for Combined Heat and Power Project Heat Exchangers

Heat recovery is a key component of the proposed Tai Xi Group CHP electrical generation project. Each genset manufacturer offers bolt-on heat exchangers and systems can be designed to recover heat from the exhaust stacks in the form of steam or hot water, or from the engine cooling water as hot water.

For mine air heating via heat recovery, the study team recommends low pressure, saturated steam generated by the CHP system. This will reduce the distribution pipe diameters and pumping requirements.

The construction of semi-centralized, heat distribution systems is likely to be costly but the paybacks are calculable, measurable, and verifiable. The equipment would be robust and reliable enough to operate for more than 20 years, potentially saving money and offsetting CO_2 emissions for many years beyond the payback period. CDM incentives also would enable the proposed project to meet investment requirements. Saving approximately 10,600 mtons/year of avoided coal consumption, at a saleable coal price of US$125/mton for the high-grade anthracite, the CHP scheme would save US$1.3 million/year (see Section 6.0 for full economic analysis).

4.4 Evaluation of Alternative Utilization Technologies

4.4.1 Onsite Uses

A 20-MWe CHP power generation project would consume the majority of the high-concentration methane predicted to be drained from these mines through 2016. However, the study team has explored alternative CH_4 utilization technologies within the Tai Xi Group, either as alternatives to CHP or to be deployed in conjunction with this scenario. Table 4.1 presents a summary of the suitability of various offsite uses.

Table 4.1: Suitability of Coal Mine Methane Onsite Utilization Options	
Method	**Suitability for Tai Xi**
A network of pipelines leading to the coal-fired thermal plant to provide the gas as an auxiliary fuel for the steam-raising boilers.	***Feasible.*** This would offset coal combustion and provide a beneficial end use of gas in excess of that required for genset power generation (as opposed to flaring).
Local gas grids to distribute the gas for domestic use in the mineworkers' housing and hot water for mine bathhouses (offset coal combustion)	***Not feasible.*** Small-scale utilization is not economical.
Localized pipelines to distribute the gas to packaged steam boilers to provide heating for buildings during winter months (offset coal combustion)	***Not feasible.*** Small-scale utilization only during winter months is not economical.

Each scenario's economic feasibility depends on the quantity and level of availability of the CMM, and also depends on the equipment and infrastructure costs involved to implement the proposed end-use project.

Some utilization scenarios appear to be piecemeal options, and are not cost-effective when compared to the CHP option. The target recipients in these cases would be best served by sending subsidiary waste heat from the CHP option to increase the overall utilization rate of heat within the proposed CHP project.

4.4.2 Offsite Uses

The study team also explored alternative CH_4 utilization technologies that could be employed off site (i.e., outside of the Tai Xi Group), again either as alternatives to CHP electric power generation or in conjunction with CHP. Table 4.2 presents a summary of the suitability of various off-site uses.

Table 4.2: Suitability of Coal Mine Methane Pipeline Utilization Options Technology	
Method	**Suitability for Tai Xi**
Installation of pipelines to send gas to the nearest industrial facility.	Technically feasible, but largely unknown at this stage.
Installation of a pipeline to the nearby small trucking town.	Technically feasible but not economical.
Installation of pipeline to send gas to the nearest city	Cost prohibitive due to length of pipeline.
Installation of pipeline to the nearest national gas pipeline.	Cost prohibitive due to length of pipeline.
Conversion of vehicles to run on CMM.	Cost prohibitive.

4.4.2.1 Pipeline Utilization Options and Conversion to Vehicle Fuel

Pipeline Utilization. During the site visit interview, the mine management and owners discussed the potential for attracting a coal chemical plant to be built centrally to all of the mines within the group (between the thermal power plant and the headquarters main office buildings). The magnitude of the plant and the nature of the chemicals to be produced were uncertain at the time. The installation of pipelines to send the gas to a potential coal chemical plant that could utilize the gas (i.e., located 0.5 to 4 km from every mine in the group) is considered technically feasible by the study team, but largely unknown at the writing of this study. Further evaluation would be required to examine the proposed project in greater detail.

In addition, the study examined the potential installation of a pipeline to the nearby town of Bei Li Gou. The small trucking town of Bei Li Gou, expected to have a population of 2,500 by the end of 2010, is located near the Tai Xi Group mines (approximately 4 km away). The volume of CH_4 required to meet the small standalone district heating needs of Bei Li Gou would represent only a small portion of the total expected drainage gas. Furthermore, a stand-alone pipeline for domestic and heating purposes in the town would not be economically feasible. However, if a pipeline to utilize any excess gas were considered in combination with a larger scale utilization scheme, such as a CHP project, the proposed project's economics might be improved, and more importantly, it could create a high degree of social responsibility between the mine owner and the town (e.g., town receives low cost fuel which benefits the community, no direct benefit to the mine(s) or mineworkers).

The installation of pipeline to send gas to the nearest city of Alashan, located 47 km from the mine, for domestic supply would reduce the consumption of natural gas in the city but due to the long pipeline distance required from the mine to the city, this scenario is considered cost prohibitive.

The installation of a pipeline to the nearest national gas pipeline for a gas clean-up and injection project would augment the natural gas supply to that region. The closest natural gas pipeline, the East–West China natural gas pipeline, runs through Alashan (47 km from the mines). During the April 2010 site visit, local officials stated they have no plans to finance any gas infrastructure in the Alashan area at this time. They will wait to assess the total gas resources in the area before making any decision. Moreover, it is unlikely that the volume of CH_4 from the mines could justify a 47-km pipeline to the East–West China pipeline in Alashan.

Conversion to Vehicle Fuel. The most feasible technical solution would be to use compressed CMM (typically 30 percent CH_4) to fuel the heavy trucks at the mines. However, the CMM is expected to exhibit very poor calorific value fuel, contributing to a very limited driving range and a complex vehicle/engine conversion to utilize the fuel. Although the main mode of mineral transport is heavy trucks with an expected increase to hundreds of vehicles driving to railhead transport, the trucks will have considerable inclines to negotiate through the Helan Mountains and the rigors of the climb through this mountain range renders such low calorific value fuel unsuitable for this application, due to the high demands placed on the vehicles.

5.0 PROJECTIONS AND PRODUCTION PLANS

An essential part of CMM utilization is to highlight and examine all likely factors that might influence the proposed project over its lifetime. Some of these factors will affect the gas resource and others will affect some point downstream of the utilization.

5.1 Projections

5.1.1 Population

By the time the Tai Xi Group achieves full production of 4.5 million mtons/year of coal in 2020, the Erdoaling mining area population is expected to be approximately 5,000 resident miners. In addition, because all the coal will be trucked out of the area, it is projected the population of the local town of Bei Li Gou will increase to at least 2,500 people, as its main industry is trucking.

5.1.2 Power Demand

When the mine reaches full production, there is expected to be at least 22.6 MWe of total power demand within the mining group's locality. Current base load or all uses in the locality is currently about 10 MWe. The majority of the additional electricity consumption, when full production is finally reached, will involve additional ventilation power requirements and CH_4 pumping power.

5.1.3 Ventilation

It is projected the total of all of the mines' ventilation systems will consume approximately 4 MWe of power. However, a further 2.5 MWe of ventilation power might be needed in the interim to dilute additional methane emissions before experience and technical proficiency with the methane drainage systems are achieved.

In order to evaluate the Tai Xi Group's ventilation requirements and power consumption, the study estimated the rate of total liberation of methane for full coal production rates onto a shortwall. For two shortwalls producing a total of 300,000 mtons/year, the minimum liberation rate estimate is 736 l/sec CH_4.

Assuming 50 percent of the gas would be captured off each shortwall by the CH_4 drainage system (184 l/sec), the remaining CH_4 would then have to be diluted to safe levels by airflow (184 l/sec). The study team estimates a 1.5 percent limit for methane in air in Chinese return roadways to determine how much airflow would be needed to keep the methane concentration at two-thirds of this level (i.e., 1.0 percent).[13] Using this method, the airflow required on a shortwall with 50 percent CH_4 capture achieving its full production rate of 3,260 mtons/week (for a 46-week year) would equate to 18 m^3/s per shortwall.

The study team developed a model using the Mine Ventilation Services (MVS) network-modeling program to simulate a single pair of drifts supplying air for two shortwalls within a mine, each with: 18

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[13] This method enables the airflow to cope with emission "spikes," where variations of this magnitude can often occur due to factors such as cut-outs, gob collapse, barometric pressure change, and rapid emissions from the floor.

m^3/s of airflow, 36 m^3/s of development air, and 20 m^3/s of pit-bottom air leakage. Another 8 m^3/s was apportioned to represent surface airlock leakage.

The model projects a total of 100 m^3/s of ventilation air flow rate at the surface fan, which requires 2.89 kPa of pressure to draw sufficient airflow around the mine. The modeling results show that 289 kW of air power is required for an output of 300,000 mtons/year of coal. At a typical fan efficiency of 70 percent, this would require a fan shaft power of 413 kW and a motor power consumption of 435 kWe to make air flow around the mine at these rates and distribution pattern.

For the full 4.5 million mtons/year of coal production, the ventilation requirements of a single 300,000-mton/year mine were then scaled-up (multiplied by 15) to determine the total airflow requirements of the 4.5 million mton/year Tai Xi Group.

This result indicates that the total ventilation power consumption could approach 6.5 MW when the methane drainage capture efficiency is at 50 percent. This means that engineers should install in the region of 7.5 MW of power capacity. See Figure 1.8 for a model used to calculate the required mine ventilation power.

5.2 Gas Capture and Drainage

A projection of percentage gas capture shows a commensurate rapid increase up through the end of 2013. Gas capture for the next 20 years is projected to be stable following the initial increase. The projection of the gas capture shows a rapid increase in plant capacity demand up through the end of 2020 (see Table A-4 in the Appendix).

6.0 PROJECT ECONOMICS

6.1 Project Costs

CMM capture and utilization project economics usually do not include the cost of drainage system installation, or the ongoing costs of expanding and operating the system. The drainage system installation is considered a “sunk cost” because it’s typically viewed as an operational necessity, and mining would not be able to continue at safe and profitable rates unless a drainage system was installed, operated, and continually maintained. Therefore, for this analysis the discounted cash flow economics will only apply to the proposed CMM utilization project. However, certain capital costs for items such as high-quality drilling equipment are included because the mine will have to purchase and operate this equipment simultaneously with the start of the proposed project.

6.1.1 Methane Capture System Capital Costs

The study team has observed that many underground drilling operations in China use inexpensive but poor quality (low strength steel) drilling rods and bits. The use of this type of equipment can cause significant delays because of frequent failures. High-quality drilling equipment will be required to deliver reliable drilling schedules, which are necessary if the Tai Xi Group’s expected productivity levels are to be met. Typical high strength, high quality equipment is likely to cost about US$150,000 per mine (one drill rig per shortwall, plus spare parts). This equates to a total CAPEX for the group of about US$2.25 million (30 drill rigs, plus spares). This calculation is based on seven of the 10 mines in the group having two working shortwalls at any one time, one mine having two shortwalls and one having three shortwalls (15 in total) and producing 150,000 mtons per year from each shortwall. Each shortwall would require its own drill rig. The equipment would be expected to last for at least 5 years.

The current and planned surface methane extraction plants (pump stations) will require considerable expansion and design changes if they are to cope with the expected CH_4 liberation volumes and still deliver adequate suction pressure. At full coal production, at the required level of drainage, total power consumption for the Tai Xi Group’s CH_4 extraction plants is expected to be between 5 and 7 MWe. Plant capacity of some 9 MW should be installed to ensure that standby equipment is present at each extraction plant.

Other underground capital, such as main pipelines in the roadways, will need to be determined on a per mine basis with the input of the mining group, and therefore were excluded from this analysis.

6.1.2 Methane Capture System Operating Costs

Cross-measure drilling is labor intensive. The process operates contiguously with shortwall retreat, so it is directly related to the rate of coal production and therefore, labor will be a major operating cost. Yearly manpower requirements to operate a successful methane drainage system at each 150,000 mton/year shortwall, would be a total of 15 men per 300,000 mtons/year of coal production; mines that produce 600,000 mtons/year will require 30 men. Consequently, a total of 225 men will be required for the full coal production level of 4.5 million mtons/year by 2020. Other costs will arise from personnel training which should consist of approximately one week each of surface training and underground training. Typically, five men per week could be training underground. Twenty men could be trained on the surface per week. Alternatively, a buddy system could quickly be established underground so multiple teams could be more cost-effectively trained as quickly as in the classroom and workshop once a critical mass of trained workers have been established. The drill rigs are portable and non-intrusive, so installation and site preparation costs are minimal.

6.1.3 Combined Heat and Power Genset Utilization Project Costs

The pro-forma economic analysis is based on the installation of a high-efficiency CHP plant according to the timeline shown in Figure 4.0 and installed at a cost of $819,000 per MWe.[14] Operating costs are assumed to be US$16/MWh. Table 6.0 illustrates the estimated expenditures for the initial 10 MWe capacity that will be spent in 2010, and expenditures for installation of additional power generation will that occur the year prior to activation.

Table 6.0: Summary of CMM Recovery, Utilization and Capital and Operational Costs

Type	Cost
Capture System CAPEX	US$2.25 million
Capture System OPEX (Labor)	15 personnel/300,000 mton/year
CHP Project CAPEX	US$819,000/MWe
CHP Project OPEX	US$16/MWh

6.2 Project Revenue

Project revenue will take the form of:

- Avoided electricity imports and possible power exports
- Reduced coal combustion for mine air heating
- Reduced coal combustion in thermal power plant
- CDM incentives

In addition, the CHP equipment would be robust and reliable enough to operate for more than 20 years, potentially saving money and offsetting CO_2 emissions for many years beyond the payback period.

Installation of a CHP project to offset coal consumption would equate to approximately 10,600 mtons/year of saleable coal, at a coal price of US$125/mton for the high-grade anthracite, for a **savings of US$1.3 million/year**.

6.2.1 Revenues from Avoidance of Electricity Imports and Possible Power Exports

The study team calculates that once the proposed project is operating at 20 MWe and 90 percent overall availability, the Tai Xi Group will avoid imports of some 157,680 MWh per year of electricity. The current tariff for imported electricity is 450 RMB per MWh. This means that the mine would avoid approximately **US$10.6 million per year** over the proposed project's lifetime (see Figure 6.0).

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[14] Based on a recent quote from GE Jenbacher received around the time of the study.

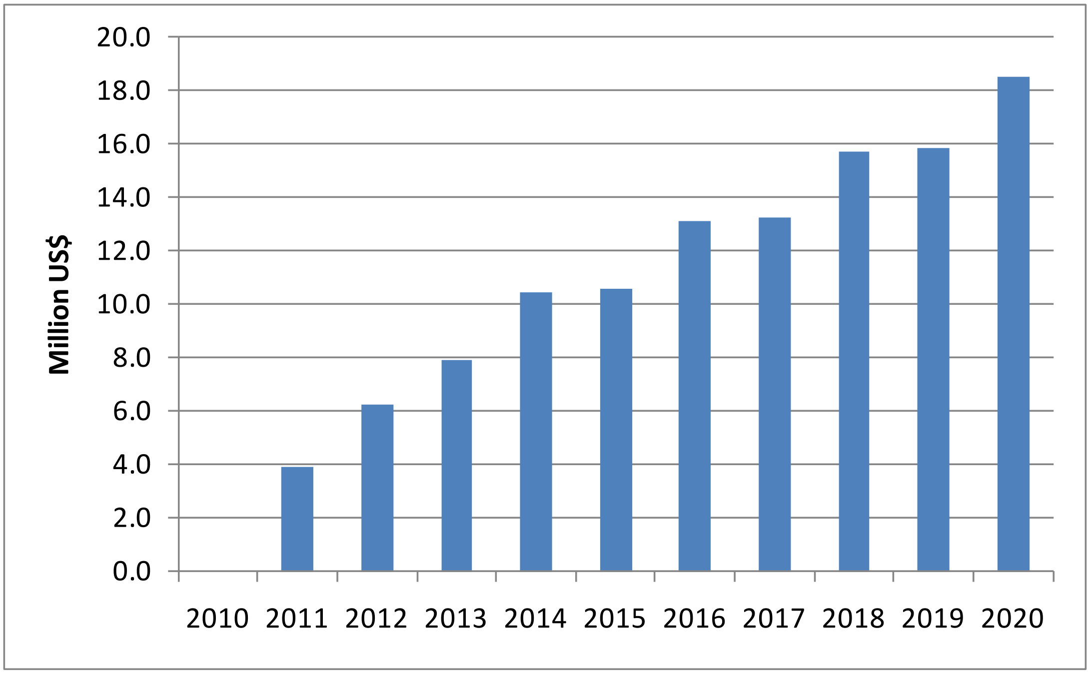

Figure 6.0: Projected Power Sales Revenue (Savings) Through Time

6.2.2 Revenue from Reduced Coal Combustion for Mine Air Heating

For mine air heating alone, every single ventilation air intake drift at the Tai Xi Group currently uses at least 360 mtons of anthracite per year. Once the group is producing 4.5 million mtons/year, this figure will increase to approximately 1,235 mtons of anthracite needed annually for every 300,000 mton/year unit. When projected across the group, this will equate to a total annual combustion of 18,500 mtons of anthracite, which at $125/mton, is **US$2.3 million in annual savings** (see Figure 6.1).

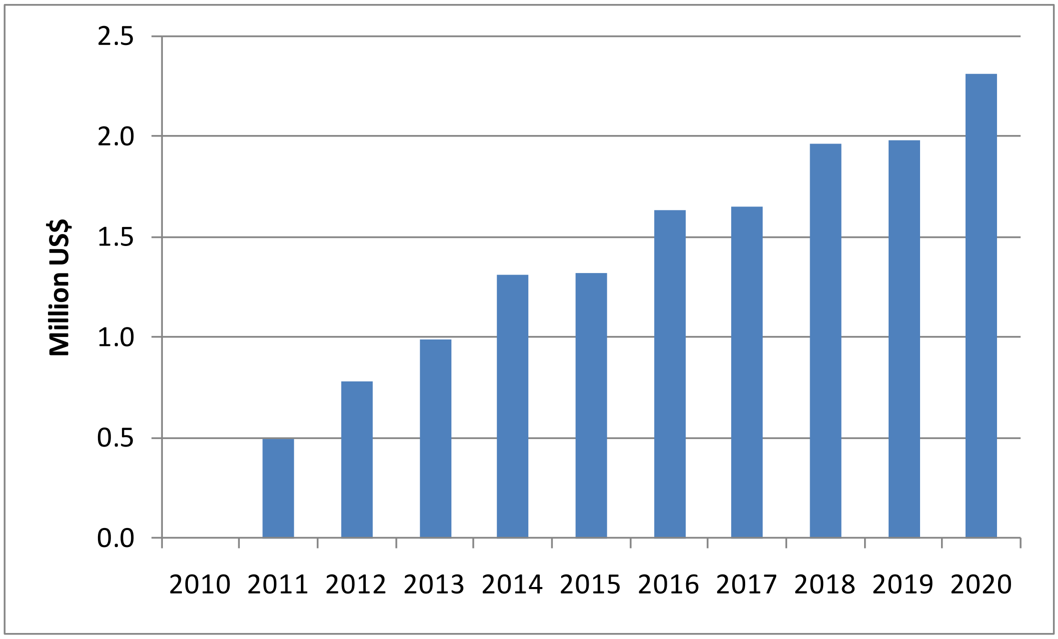

Figure 6.1: Projected Coal Sales Revenue (Savings) Through Time

Table A-6 in the Appendix summarizes the thermal requirement for the Tai Xi Group's shaft heating and the coal savings that could be realized by the proposed project.

6.2.3 Revenue from Potential Sale of Certified Emission Reductions or Verified Emission Reductions Sales

Emissions of more than 5 million mtons CO_2e could be reduced from the baseline condition through 2020 should the project proceed as presented. At US$8/mtons CO_2e that would be **US$40 million**, which would significantly enhance the project economics as discussed below in the discounted cash flow analysis.

6.3 Discounted Cash Flow Analysis

Table 6.1 summarizes the parameters used together with the previously determined revenue and cost streams to calculate the end use scenario project cost, revenue, discounted cash flow, and IRR.

Table 6.1: Parameters Used in Discounted Cash Flow Analysis	
Emission reduction factor, tonnes of carbon dioxide equivalent/square meters of methane (tCO_2e/m^3 CH_4)	0.01407
Emission reduction factor net of CO_2 produced (tCO_2e/m^3 CH_4)	0.01223
CH_4 density (tonne/m^3)	0.00067
CH_4 CO_2 emission factor, tones of carbon dioxide equivalent/tones of methane (tCO2/tCH4)	2.75
Energy content of pure CH_4 megajoules per cubic meter (MJ/m^3)	35.55
Internal Combustion Engine (IC) electrical conversion efficiency	43%
Percent of CH_4 drained delivered as fuel to generators (greater than25%)	64%
Percent generators on-line	90%
Low specific emissions (m^3/tonne mined)	38.05
High specific emissions (m^3/tonne mined)	68.24
Mid specific emissions (m^3/tonne mined)	53.15
Sales price of gas to CDM project	-
Power sales price from CDM project to mine ($/MWhr)	67.16
Price of anthracite coal ($/tonne)	125.00
CAPEX for CHP power plants (M$/MW)	0.819
CAPEX for power plants (no CHP) (M$/MW)	0.783
Range of operating costs for power generator ($/MWhr)	16.00
CO_2 emissions factor for northern China (tCO_2e/MWhr)	1.03
CO_2 emission factor for anthracite (tCO_2e/tonne)	2.57
Energy content of Anthracite (MJ/kg)	26.34

The table below shows the NPV at three different discount factors, the IRR, and the time to pay back the investment (payout) of the proposed project's cash flow under four scenarios:

- *Scenario 1: Full project implementation including CHP with CER sales.*
- *Scenario 2: Full project implementation including CHP with no CER sales.*
- *Scenario 3: Power generation only with CER sales and no CHP.*
- *Scenario 4: Power generation only with no CHP or CER sales.*

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
NPV @ 10%	$44,130,228	$4,011,118	$36,871,239	($1,727,038)
NPV @ 15%	$30,745,384	$1,388,787	$25,448,392	($2,795,856)
NPV @ 20%	$21,749,799	($275,214)	$17,788,574	($3,402,261)
IRR	72%	19.0%	64.7%	5.2%
Payout (years)	3	6	3	9

Based on the revenue analysis, Scenarios 1 and 3 represent the highest returns and shortest payback periods. While the importance of CER sales in these scenarios resulted in the most favorable revenue scenarios, Scenario 2 (i.e., without CER sales) also provides favorable return on investment and relatively short pay back due to the energy efficiency gains from the application of waste heat recovery. Only Scenario 4 (power generation and no CHP or CER sales) resulted in negative NPV.

6.4 Economic Sensitivity Analysis

The sensitivity of the project economics to variations in six uncertain parameters shows the results of high, middle and low values on the IRR relative to the base case (i.e., uncertainty). The base case uses the most likely value and assumes the installation and use of CHP. The parameters of interest are shown in the table below.

Parameter	Low	Mid	High
Specific emissions (m^3/mton mined)	38.05	53.15	68.24
Power price (US$/kWhr)	53.73	67.16	80.60
CAPEX (million US$/MWe)	0.66	0.82	0.98
OPEX (US$/MWhr)	14.40	16.00	17.60
CER price (US$/t$CO_2$e)	8.00	12.00	16.00
Coal price (US$/mton)	100.00	125.00	150.00

The uncertainty in the specific emissions is based on the variation of gas content of the coals together with the CH_4 liberation model. The power price, capital cost and coal price were varied by +/- 20 percent and the operation costs were varied by +/- 10 percent. The results are shown in Figure A-1 and Figure A-2 in the Appendix.

The project with CERs is financially attractive no matter the downside scenarios; however, assuming an IRR hurdle rate of 15 percent, the project without CERs would fail given both a low power price scenario or a high capital cost scenario.

Interestingly, the large potential variation in specific emissions had little effect on the IRR in either case. This is because, as mining progresses the actual, as opposed to predicted, specific emission rate will become apparent and will affect the rate at which power generation is installed. Figures A-3, A-4, and A-5 show this graphically; where the base case (mid-case specific emission rate) has an installed capacity of 35 MWe, the low case has an installed capacity of 25 MWe and the high case has an installed capacity of 45 MWe. The relative return on investment remains about the same because as investment goes up so does revenue. The difference between the three emission rate scenarios is related to the timing of the investment to build the power generation. The study team used the logic that no new 5-MWe plant would be built if the projected gas rate (power generation potential) of a given year is less than 30 percent in excess of the currently built capacity.

7.0 REGULATORY ISSUES

7.1 Gas Ownership Rights / Land Access

All minerals are owned by the Peoples Republic of China, and the coal gas within the mining concession is under the control of the coal lease owner.

Surface access is not an issue, as there is no residential occupation in the mining area aside from mine personnel and their families. There is virtually no farming or other use of the land other than for mining operations.

7.2 Ventilation and Drainage Regulations

In June 2006, the State Council issued “Opinions on Speeding up CBM/CMM Extraction and Utilisation,” which clarified the principle of gas extraction prior to coal mining as well as gas control and utilization.[15] Key aspects of this policy related to CMM include:

- The maximum CH_4 concentration in active workings is required to be 1.0 percent or less. The maximum CH_4 concentration in the return airway is 1.5 percent (2.5 percent for a non travelling return). If these values are exceeded, mining activities need to cease until the levels return to below this concentration limit. Therefore, implementation of drainage activities at the Tai Xi Group mines will be crucial for safe and efficient coal mining operations.
- CMM must be drained prior to mining (uncertain to what extent the CMM must be drained).
- 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 CMM, mining activity must be suspended.
- Coal mine owners and operators have a legal responsibility to ensure that these standards are followed.

In April 2008, the Ministry of Environmental Protection issued an “Emission Standard of Coalbed Methane/Coal Gas Methane.”[16] For new coal mines and surface drainage systems the regulation became effective on July 1, 2008. For existing mines and drainage systems the regulation became effective on January 1, 2010. In summary, the standard includes the following guidance:

- Coal mine drainage systems with gas concentrations of greater than 30 percent CH_4 or higher are prohibited from venting to the atmosphere and must either utilize or flare the gas.
- If the CH_4 content in the drained gas is less than 30 percent, it may be vented.

While outside of the scope of this report, the team identified several potential issues with the emission standard which might serve as an inverse incentive to produce low quality CMM (below 30 percent) which should be further evaluated in terms of the potential impact on the Tai Xi Group. The two primary concerns with the standard include:

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[15] www.chinasafety.gov.cn/zuixinyaowen/2008-08/08/content_285865.htm

[16] http://www.mep.gov.cn/pv_obj_cache/pv_obj_id_ED0BE21DD51F184D15B7BC4F1FF7C8A923110200/filename/W020080416455262165735.pdf

- No requirement to invest in utilization or flare equipment.
- The requirement to use gas greater than 30 percent CH_4 removes the proposed project from obtaining CDM registration because it may violate the “surplus” requirement of additionality.

Because the CH_4 content of drained gas is variable, producing below 30 percent CH_4 will likely cause potentially explosive gas mixtures to be periodically transported through the mine. Gas with less than 30 percent CH_4 should not be utilized and yet this has been observed to be common practice in China. Explosion mitigation requirements are being developed for use throughout China to allow the safe transport and utilization of CMM in the explosive range.

China’s National Development and Reform Commission (NDRC) set forth CMM utilization requirements in 2008 that require coal mines to utilize all gas above 30 percent CH_4 concentration as of July 2010. The regulation could affect the eligibility of CMM projects based on the surplus additionality argument in CDM and international voluntary carbon markets.

7.3 Clean Development Mechanism Additionality Considerations

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

Numerous certification standards exist with approved methodologies for coal mine methane projects. Many of these methodologies are based on existing methodologies approved under the United Nations Framework Convention on Climate Change (UNFCCC)-accredited CDM, which is the most well-known of the international certification regimes.

During the course of conducting this study, discussions were held with the Tai Xi Group regarding how partial solutions to utilization might present an additionality issue in the context of CDM and carbon credit eligibility. For example, the Tai Xi Group is currently moving ahead with power generation using low-cost, low-efficiency domestic equipment (i.e., a total of 3 MWe using 500 kW Shen Dong gensets presently loaned to the group for a trial). As a result, to demonstrate additionality, the lower cost of Tai Xi Group power generation system might suggest limited financial barriers, while the gensets low-efficiency might suggest limited technological barriers to overcome and result in the project being unable to pass additionality hurdles.

Fundamentally, if the Tai Xi Group adopts the CHP genset plan, it has two routes to power generation:

- Option 1. Select domestic gensets that are low in cost, but employ low-efficiency technology and often offer lower operational availability rates.

- Option 2. Select high-efficiency gensets that have a much higher cost, but have very high efficiencies and offer high operational rates.

Option 1, which involves financial additionality, might be difficult to prove based on the historically low success rates for registering Chinese CMM projects under CDM rules using this approach.

Option 2, comprised of modeling of the CH_4 utilization using high-efficiency advanced technology equipment, would face a higher financial barrier from the very outset, considerably lowering IRRs. This would significantly increase the likelihood that the proposed project would qualify for carbon credits under CDM additionality rules, providing significant additional revenue to the project developers.

8.0 GREENHOUSE GAS EMISSION REDUCTIONS

The proposed project would reduce the amount of CMM liberated by capturing and combusting (oxidizing) CH_4 that would otherwise be emitted to the atmosphere. If done according to the systems and procedures of a specific certification regime, the proposed project could generate carbon offsets.

Currently, there are some 4,823 active projects in the CDM pipeline. Nearly 40 percent of the projects (1,916) active in the CDM pipeline are hosted by China. Currently, China is the number one country by issued CERs, accounting for 48 percent or 174 million CERs. China also accounts for over half of CERs expected by 2012 and 2020 (55 percent and 57 percent, respectively).[17]

Due to methane's high global warming potential, CMM projects can generate significant carbon offsets and have become one of the leading types of CDM projects. Currently, there are 68 CBM/CMM projects in the CDM pipeline—66 located in China—with total planned power generation capacity of more than 1000 MW. (The other two projects are in Mexico and India). To date, 26 of the projects submitted have been registered by the CDM Executive Board, 6 being CBM projects. The CMM projects have been issued CERs, all of which are categorized in the CMM project sub-type.

8.1 Emission Reductions from Tai Xi Group Coal Mine Methane Utilization Project

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

The reductions in GHGs attributed to the proposed project are two-fold: 1) direct combustion of CMM at the mine by the power plant engines and 2) indirect reduction of power consumption purchased by the mine from more GHG-intensive (dominantly coal-fired) energy sources off the North China Power Grid (see Table 8.0).

Table 8.0: Summary of Potential Tai Xi Group CMM Utilization Project Emission Reductions

Emission Reductions Measure	Estimated Emission Reductions (Annually)	Notes
Direct Methane Mitigation	452,255 mtons of CO_2e	Based on the proposed 20-MWe CHP electricity generation project by 2015, approximately 452,255 mtons of CO_2e per year would be mitigated via combustion of methane to produce 157,680 MWh of electricity per year.
Displacement of Fossil-Fueled, Grid-Imported Power	140,583 mtons of CO_2	During the generation process, the electricity produced will displace 140,583 MWh of fossil fueled, grid-imported electricity. The OM and BM grid factors for the North China Power Grid are 1.12 and 0.94, respectively. Thus, the combined margin grid factor is 1.03 mtons CO_2/MWh.

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

Table 8.0: Summary of Potential Tai Xi Group CMM Utilization Project Emission Reductions		
Emission Reductions Measure	**Estimated Emission Reductions (Annually)**	**Notes**
Displacement of Fossil-Fueled Heat Generation	Saving 21,203 mtons of CO_2 per heating season and 9,528 mtons of coal.	By evaluating the genset heat balance data, 0.982 MWth can be recovered per MWe of installed capacity. Assuming a 10 percent distribution system loss, 250,969 gigajoules of heat can be supplied during the six-month winter heating period (calorific value: 26.34 gigajules/mton, emission factor: 0.57 tCO_2e/mton coal).
Project Emissions	59,224 mtons of CO_2	Combustion of 37.1 million m^3 CH_4 per year with a destruction efficiency of 99.5 percent.

The study team estimates that by 2015 emissions totaling 554,816 mtons of CO_2e/year could be avoided once the initial 20-MWe CHP project is operational.[18] This total would increase to 951,113 mtons CO_2e after the addition of 15 MWe in 2013 (see Figure 8.0 and Table A-5 in the Appendix to see the emission reductions and proposed project emissions forecast through full coal production).

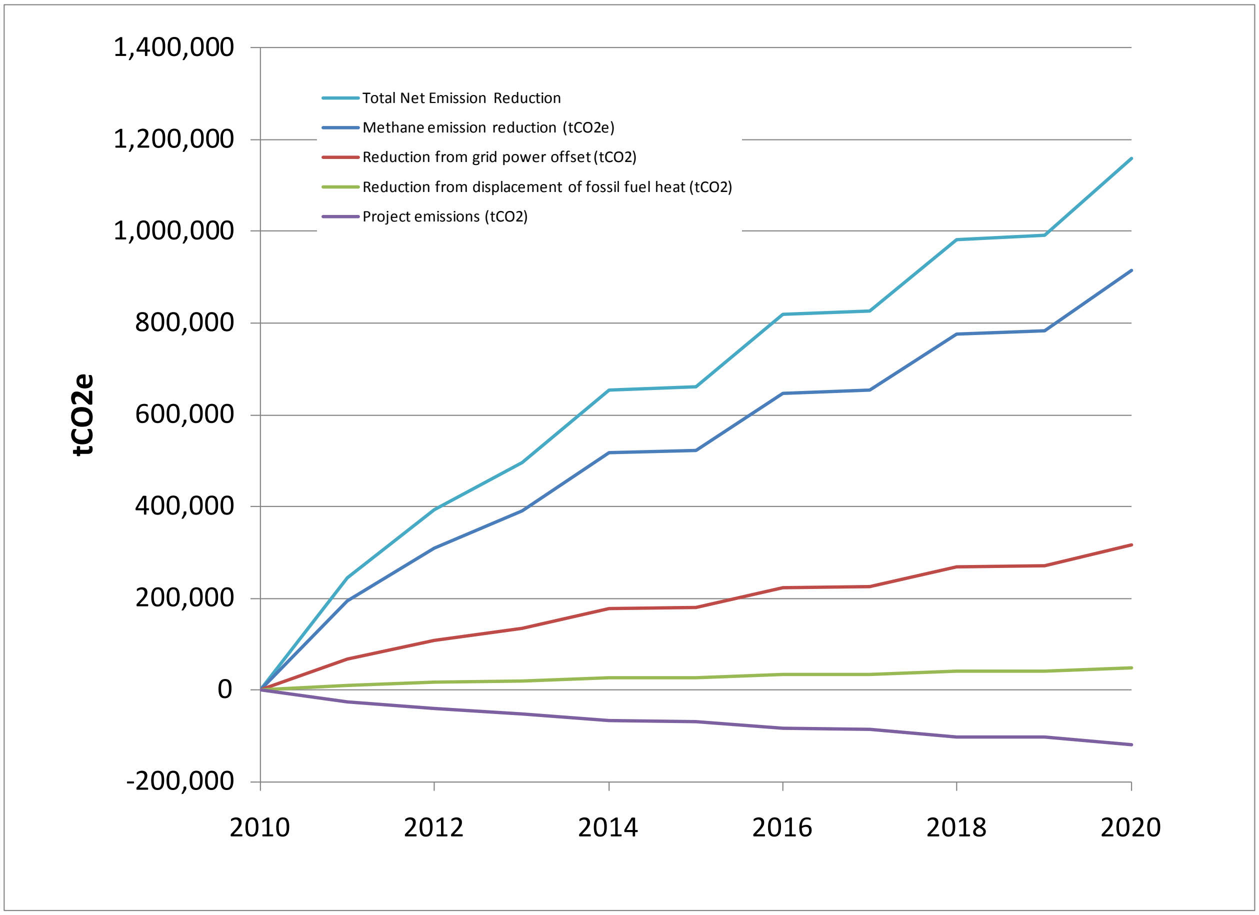

Figure 8.0: Methane Emission Reductions, Reduced Coal Use Offset Reductions and Project Emission (Carbon Dioxide Generated)

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[18] The proposed project's calculated annual emission reductions are: 452,255 + 140,583 + 21,203 – 59,224 = 554,816 mtons CO_2 per year.

9.0 SOCIAL BENEFITS

Environmental Impacts. The proposed Tai Xi Group methane capture and utilization project will have negligible environmental impacts. The proposed CHP power generation project is expected to result in a small but manageable local increase in carbon monoxide (CO) and nitrogen oxide (NOx) emissions from the IC engines. Impacts from increased coal production, traffic, and infrastructure construction related to the proposed project are considered to be negligible. In addition, environmental improvements at the mines will benefit Alashan City's special environmental interest due to its desert climate, and includes a southern segment of the Gobi Desert and the Helan Mountain National Reserve, containing sensitive significant ecological and cultural resources, lies immediately east of the area, covering 261 square miles, with the highest peak measuring 11,700 feet tall.

Air Quality. The proposed project is expected to have net positive overall impact on local and regional air quality. The proposed CHP project will significantly reduce the amount of coal burned for heat and power as mining expands and thereby, helps maintain the currently good air quality of the region. Local air quality will improve as coal combustion is reduced, and working environments will improve due to efficient mine air heating and building, workshop, and bathhouse heat inputs from the proposed project activities. Moreover, civic pride will be achieved with the knowledge that hundreds of thousands of mtons of carbon dioxide equivalent per year are being avoided. Power generation utilizing CMM fuel is far cleaner than that fueled by coal, which is the dominant fuel source for power generation in the province.

Increased Coal Production. By enhancing the efficiency of CMM drainage, the proposed project could facilitate and reduce the costs of coal production at Tai Xi Group. There is little chance that the coal under the Tai Xi Group's license will not be mined, as China has become a net importer of coal and with this anthracite being unusually valuable. Coal production and consumption in China has risen by more than 9 percent from 2008 to 2009.

Increased Traffic. The CMM drilling and drainage subcomponents are not expected to result in significantly increased traffic above or inside the mine. The drilling and pipeline equipment could be delivered in several large truck loads. However, overall local truck traffic is expected to increase significantly when the mines are producing at full capacity, as the Tai Xi Group is planning to truck the entire 4.5 million mtons of coal per year from the mining region. Overall, the proposed project is expected to have negligible and easily manageable impacts on the traffic at Tai Xi Group. No additional road construction or modification in traffic patterns would be needed to accommodate the proposed project.

Increased Employment. As a capital-intensive activity, the proposed CMM drainage and utilization project will increase employment opportunities at the local level (at least 225 jobs related to the drainage system alone), allowing the workforce to become technically proficient in areas such as CH_4 drainage and surface CH_4 drainage plants. In addition, reciprocating engine and genset maintenance workers, electrical distribution specialists, heat distribution specialists, technicians, engineers, and managers will all be required once utilization is introduced. Training needs would benefit local education institutions, introducing new facets of specialized engineering to the community.

Health and Safety. If implemented, the proposed project would result in improved safety of the mineworkers when efficient CH_4 drainage systems are introduced into the Tai Xi Group of mines.

10.0 **CONCLUSIONS AND RECOMMENDATIONS**

The proposed CMM drainage and utilization improvement project at Tai Xi Group has considerable positive technical, economic, and environmental merits. The proposed project would improve the safety and technical efficiency of CMM drainage and transport at the mine, resulting in production of CMM with significantly higher methane concentration that is more feasible to utilize. By utilizing CMM supplies that currently are being vented, the proposed project would convert a cleaner energy source to power and help to reduce overall GHG emissions related to the mine.

The Tai Xi Group is pursuing a fast-track endeavor to upgrade and consolidate twelve small mines to increase their coal output to 4.5 million mtons of very high gas content anthracite by the end of 2020. This significant undertaking will require rigorous underground environmental planning to ensure that ventilation and methane drainage requirements are met. Moreover, the improvements will contribute to an attractive CMM recovery and utilization project opportunity.

Findings in this feasibility study show that a CHP utilization project, consisting of several phases totaling up to 35 MWe implemented over the next ten years, represents the most suitable scenario for the Tai Xi Group. The proposed projects will be designed to incorporate power generation combined with additional thermal capture and utilization for drift heating, facilities, and mine buildings.

The study team envisions that three to five surface methane drainage plants will be constructed, each able to drain gas from two to three mines within the group. These plants (varying in size and capacity) will be permanent but constructed in a modular fashion, allowing them to stand the rigors of the harsh environment yet easily deconstructed to move to a new location, as required. One of the plants will aggregate gas drainage from a group of northern mines and the other plant from a group of the southern mines. However, because the Tai Xi Group is in the very early stages of developing a long-term project site plan, and taking into account the complexity of designing such an ambitious plan, the the feasibility study did not assess the viability of networking all of the gas plants (three to five) with area-wide utilization schemes.

It is recognized by the Tai Xi Group that mining this coal will be a hazardous exercise and extreme care must be given to the operation of the methane drainage system. Because the previous mining rates were less than half what was originally proposed by management (see Table 1.8 compared to Table 1.7), there is significant uncertainty regarding the ultimate methane emission rate to be expected. Therefore, the Tai Xi Group must remain flexible in their capital expenditure schedule should the emissions be significantly greater or less than forecast in this study. Plans are underway to construct new mines that will fill the production gap expected to occur beginning in 2018.

The development of a CHP project at the Tai Xi Group mines will achieve several important benefits:

- Destroying CH_4 will reduce annual CO_2 emissions by approximately 576,000 mtons CO_2e.
- Using CMM to generate power for ventilation and methane pumping will help the Tai Xi Group mines meet their growing electricity requirements. When they reach full production, the mines and their general location are expected to demand at least 22.6 MWe.
- Using CMM for electricity generation will also help the mines achieve energy supply security. The mines are limited in their ability to import electricity (a maximum of 7 MWe) from the national power grid.

- Using waste heat recovery will enable the mines to save more than 10,000 mtons of coal combustion for mine air heating during six sub-zero temperature months of the year.

The estimated financial performance of the proposed Tai Xi Group recovery and utilization project is robust, while the risks of increased capital and operating costs, reduced power prices, and other variables appear to be moderate and manageable. If successful, the advanced techniques, equipment, and management practices demonstrated by the proposed project could be applied broadly by other coal mine operators in China, resulting in significantly increased CMM utilization and reduced GHG emissions.

Recommended Next Steps

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

- Perform a detailed technical and economic analyses (e.g., project pro forma) and due diligence to evaluate the feasibility and structure of pursuing a CMM recovery and utilization project.
- Consult, evaluate and make any necessary modifications to the proposed project design contained in this study.
- Obtain corporate decisions to evaluate and recommend the potential advancement of a CMM recovery and utilization project.
- Obtain necessary approvals from the proposed project's technical, financial, social, and environmental regulating authorities.
- Contact equipment and service providers to obtain site-specific quotes and timetables for the drilling, pipeline, and power generation equipment and installation, and operation.
- Conduct project scoping and training visits to other mine locations in China, the United States, and Australia, where similar practices and equipment is in operation.
- Register the proposed project with CDM approval authorities.

APPENDIX

Table A-1: Coal Test Borehole Data

Drilling Number	SST A62	SST A63	SST A61	SST A61上	SST -A51上	SST A51	SST A52	SST A53	SST B61	SST B51
Drilling locations	一采区1600水平	一采区1600水平	一采区1600水平	一采区1600水平	一采区1500水平	一采区1500水平	一采区1500水平	一采区1500水平	二采区1600水平	二采区1500水平
Seam	2-2	2-3	2-1	2-1 upper	2-1 upper	2-1	2-2	2-3	2-1	2-1
Orifice elevation	1,600	1,600	1,600	1,600	1,500	1,500	1,500	1,500	1,600	1,500
Orifice elevation angle drill	26°	41°	30°	35°	25°	25°	19°	20°	21°	20°
Drilling Depth (m)	19.2	20.8	30	28.8	32	30.4	44.8	24	42	25
Sealing Length (m)	12.6	16.5	20	10	21	20	29.5	19.5	20	20
Coal Hole Length (m)	6.6	3.1	10	18.8	11	10.4	15.3	4.5	22	5
Hole diameter (mm)	75	90	90	90	75	90	90	75	90	90
Final hole diameter (mm)	75	90	75	90	75	90	75	75	75	75

Table A-2: Reserve Category by Seam and for Entire Yanan Coal Group

Seam	Unit Name	Area m^2	Thickness m	Density t/m^3	Angle	Gas Content $m^3 \cdot t^{-1}$	Coal Resource t	Gas Resource m^3
Yanan Coal Group	I_{A1}	10,539,000	10.8	1.4	48°	10.5	238,144,360	2,500,515,780
	II_{A2}	1,618,000	2.5		52°	7.0	9,198,237	64,387,657
	III_{B1}	7,923,000	11.2		38°	18.0	157,231,197	2,830,161,545
	IV_{B2}	794,000	2.5		48°	11.0	4,153,150	45,684,654
	V_{B2}	2,713,000	2.5		40°	12.0	12,395,495	148,745,939
	VI_{C1}	12,323,000	10.5		30°	18.0	209,171,809	3,765,092,555
	VII_{C2}	12,771,000	2.0		20°	20.0	38,053,720	761,074,403
	$VIII_{D1}$	2,317,000	10.2		15°	23.0	342,539,345	7,878,404,935
	IX_{D2}	2,355,000	4.3		15°	23.0	14,677,214	337,575,921
	Total						1,025,564,527	18,331,643,389
二$_1$ (2-1)	I_{A1}	6,601,000	7.8	1.4	45°	13.0	101,940,643	1,325,228,360
	II_{A2}	2,095,000	1.0		50°	8.5	4,562,938	38,784,973
	III_{A2}	3,608,000	1.4		50°	9.0	11,001,581	99,014,230
	IV_{B1}	3,827,000	1.2		40°	14.0	8,392,933	117,501,068
	V_{B2}	3,345,000	6.5		38°	17.5	38,628,280	675,994,899
	VI_{B2}	4,335,000	2.0		40°	15.0	15,845,034	237,675,505
	VII_{C1}	3,737,000	6.0		30°	21.0	36,246,974	761,186,447
	$VIII_{C2}$	20,963,000	1.3		20°	20.0	40,601,213	812,024,255
	IX_{D2}	4,715,000	2.0		15°	23.0	13,667,716	314,357,471
	Total						270,887,312	4,381,767,208
二^2 (2-2)	I_{A2}	8,823,000	1.7	1.37	48°	11.6	31,432,230	364,613,873

Table A-2: Reserve Category by Seam and for Entire Yanan Coal Group

Seam	Unit Name	Area m^2	Thickness m	Density t/m^3	Angle	Gas Content $m^3 \cdot t^{-1}$	Coal Resource t	Gas Resource m^3
	II_{B2}	4,457,000	1.5		35°	18.5	11,032,156	204,094,887
	III_{B2}	4,175,000	1.5		33°	14.8	10,230,030	151,404,443
	IV_{C2}	9,033,000	0.9		20°	22.6	11,852,481	267,866,072
	V_{C2}	3,931,000	1.4		30°	18.0	8,706,047	156,708,849
	VI_{D2}	1,603,000	0.7		12°	19.0	1,571,621	29,860,793
	Total						74,824,565	1,174,548,917
$II_{3\,(2\text{-}3)}$	I_{A2}	5,732,600	2.0	1.39	58°	13.0	31,074,787	423,674,356
	II_{B2}	2,745,000	2.4		38°	18.5	11,475,546	212,297,597
	III_{C2}	4,485,000	1.4		30°	22.0	10,221,978	224,883,526
	Total						52,772,311	860,855,479
$II_{4\,(2\text{-}4)}$	I_{A2}	8,635,000	1.7	1.39	48°	10.4	30,494,054	317,138,164
	II_{B2}	882,000	1.2		40°	14.2	1,920,484	27,270,871
	III_{C2}	1,142,000	0.7		38°	16.0	1,309,369	20,949,907
	Total						33,723,907	365,358,942

Table A-3: Predicted High, Low and Average Gas Release and Required Ventilation Air and Power to Maintain Safe Levels of Methane in the Workings											
Year	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Coal Production (million tonnes)	0.75	1.5	1.8	2.1	2.4	2.7	3	3.3	3.6	3.9	4.5
Total gas release (m^3)	51,181,200	102,362,400	122,834,880	143,307,360	163,779,840	184,252,320	204,724,800	225,197,280	245,669,760	266,142,240	307,087,200
Gas release in ventilation (m^3)	40,944,960	71,653,680	73,700,928	71,653,680	81,889,920	92,126,160	102,362,400	112,598,640	122,834,880	133,071,120	153,543,600
Required total ventilation flow (m^3/s)	1,171	1,137	1,144	1,137	1,171	1,205	1,239	1,272	1,306	1,340	1,408
Average VAM concentration (%CH_4)	0.11	0.20	0.20	0.20	0.22	0.24	0.26	0.28	0.30	0.31	0.35
Ventilation air power required (MWe)	2.9	2.7	2.7	2.7	2.9	3.2	3.5	3.8	4.1	4.4	5.1
VAM emission (tCO_2e)	576,096	1,008,167	1,036,972	1,008,167	1,152,191	1,296,215	1,440,239	1,584,263	1,728,287	1,872,311	2,160,358
Total gas release (m^3)	28,539,000	57,078,000	68,493,600	79,909,200	91,324,800	102,740,400	114,156,000	125,571,600	136,987,200	148,402,800	171,234,000
Gas release in ventilation (m^3)	22,831,200	39,954,600	41,096,160	39,954,600	45,662,400	51,370,200	57,078,000	62,785,800	68,493,600	74,201,400	85,617,000
Required total ventilation flow (m^3/s)	1,051	1,032	1,036	1,032	1,051	1,070	1,089	1,108	1,127	1,145	1,183
Average VAM concentration (%CH_4)	0.07	0.12	0.13	0.12	0.14	0.15	0.17	0.18	0.19	0.21	0.23
Ventilation air power required (MWe)	2.1	2.0	2.0	2.0	2.1	2.2	2.4	2.5	2.6	2.8	3.0
VAM emission (tCO_2e)	321,235	562,161	578,223	562,161	642,470	722,779	803,087	883,396	963,705	1,044,014	1,204,631
Total gas release (m^3)	39,860,100	79,720,200	95,664,240	111,608,280	127,552,320	143,496,360	159,440,400	175,384,440	191,328,480	207,272,520	239,160,600
Gas release in ventilation (m^3)	31,888,080	55,804,140	57,398,544	55,804,140	63,776,160	71,748,180	79,720,200	87,692,220	95,664,240	103,636,260	119,580,300
Required total ventilation flow (m^3/s)	1,111	1,085	1,090	1,085	1,111	1,137	1,164	1,190	1,216	1,243	1,295
Average VAM concentration (%CH_4)	0.09	0.16	0.17	0.16	0.18	0.20	0.21	0.23	0.25	0.26	0.29
Ventilation air power required (MWe)	2.5	2.4	2.4	2.4	2.5	2.7	2.9	3.1	3.4	3.6	4.1
VAM emission (tCO2e)	448,665	785,164	807,598	785,164	897,331	1,009,497	1,121,663	1,233,830	1,345,996	1,458,162	1,682,495

Table A-4: Tai Xi Group Gas Emission Analysis Summary of Results

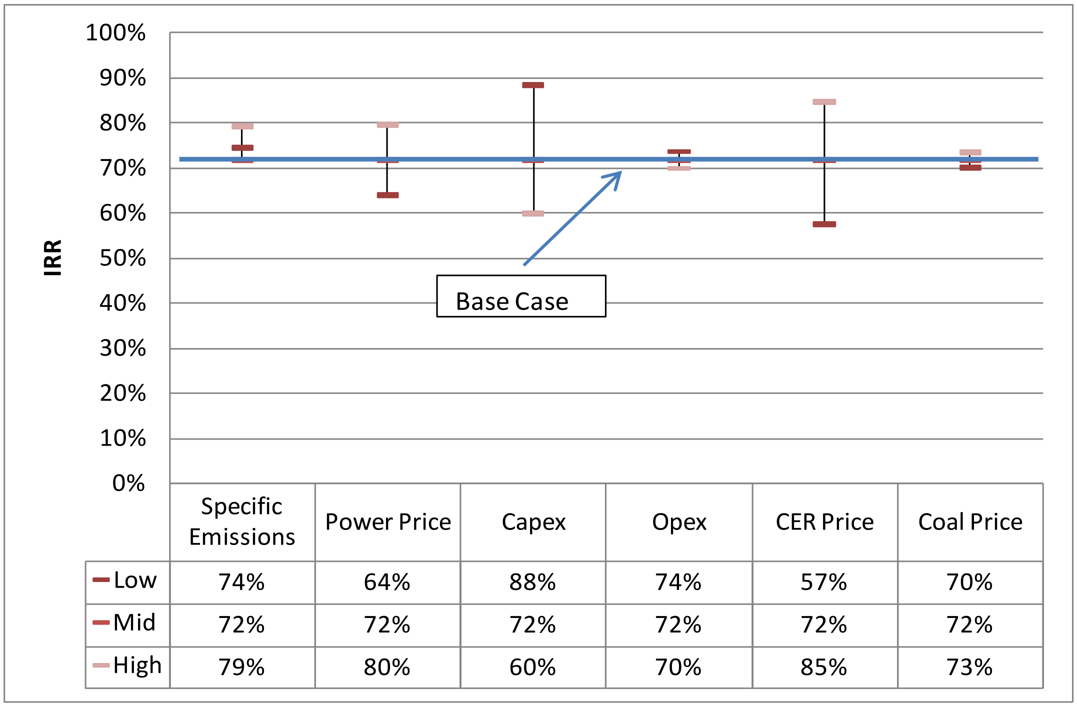
Scenario	Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
High	Total gas release (m^3)	51,181,200	102,362,400	122,834,880	143,307,360	163,779,840	184,252,320	204,724,800	225,197,280	245,669,760	266,142,240	307,087,200
	Total gas drained (m^3)	10,236,240	30,708,720	49,133,952	71,653,680	81,889,920	92,126,160	102,362,400	112,598,640	122,834,880	133,071,120	153,543,600
	Total gas suitable for utilization (m^3)	6,551,194	19,653,581	31,445,729	45,858,355	52,409,549	58,960,742	65,511,936	72,063,130	78,614,323	85,165,517	98,267,904
	Total gas utilized (m^3)	5,896,074	17,688,223	28,301,156	41,272,520	47,168,594	53,064,668	58,960,742	64,856,817	70,752,891	76,648,965	88,441,114
	Installed capacity (MWe)	6.35	9.53	15.24	22.23	25.40	28.58	31.76	34.93	38.11	41.28	47.63
	Average annual operational load (MWe)	5.72	8.57	13.72	20.01	22.86	25.72	28.58	31.44	34.30	37.15	42.87
Low	Total gas release (m^3)	28,539,000	57,078,000	68,493,600	79,909,200	91,324,800	102,740,400	114,156,000	125,571,600	136,987,200	148,402,800	171,234,000
	Total gas (m^3)	5,707,800	17,123,400	27,397,440	39,954,600	45,662,400	51,370,200	57,078,000	62,785,800	68,493,600	74,201,400	85,617,000
	Total gas suitable for utilization (m^3)	3,652,992	10,958,976	17,534,362	25,570,944	29,223,936	32,876,928	36,529,920	40,182,912	43,835,904	47,488,896	54,794,880
	Total gas utilized (m^3)	3,287,693	9,863,078	15,780,925	23,013,850	26,301,542	29,589,235	32,876,928	36,164,621	39,452,314	42,740,006	49,315,392
	Installed capacity (MWe)	3.54	5.31	8.50	12.40	14.17	15.94	17.71	19.48	21.25	23.02	26.56
	Average annual operational load (MWe)	3.19	4.78	7.65	11.16	12.75	14.34	15.94	17.53	19.12	20.72	23.90
Average	Total gas release (m^3)	39,860,100	79,720,200	95,664,240	111,608,280	127,552,320	143,496,360	159,440,400	175,384,440	191,328,480	207,272,520	239,160,600
	Total gas (m^3)	7,972,020	23,916,060	38,265,696	55,804,140	63,776,160	71,748,180	79,720,200	87,692,220	95,664,240	103,636,260	119,580,300
	Total gas suitable for utilization (m^3)	5,102,093	15,306,278	24,490,045	35,714,650	40,816,742	45,918,835	51,020,928	56,123,021	61,225,114	66,327,206	76,531,392
	Total gas utilized (m^3)	4,591,884	13,775,651	22,041,041	32,143,185	36,735,068	41,326,952	45,918,835	50,510,719	55,102,602	59,694,486	68,878,253
	Resource power generation capacity (MWe)	**4.95**	**7.42**	**11.87**	**17.31**	**19.79**	**22.26**	**24.73**	**27.20**	**29.68**	**32.15**	**37.10**

Table A-5: Forecast Emission Reductions for the Tai Xi Group

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Coal production (million tonnes)	0.75	1.5	1.8	2.1	2.4	2.7	3	3.3	3.6	3.9	4.5
Total gas release (m^3)	39,860,100	79,720,200	95,664,240	111,608,280	127,552,320	143,496,360	159,440,400	175,384,440	191,328,480	207,272,520	239,160,600
Captured gas resource (m^3)	5,102,093	15,306,278	24,490,045	35,714,650	40,816,742	45,918,835	51,020,928	56,123,021	61,225,114	66,327,206	76,531,392
Total gas utilized at 90% runtime (m^3)	4,591,884	13,775,651	22,041,041	32,143,185	36,735,068	41,326,952	45,918,835	50,510,719	55,102,602	59,694,486	68,878,253
Installed gas utilization at 90% runtime (m^3)	0	18,566,971	18,566,971	37,133,942	37,133,942	37,133,942	37,133,942	55,700,913	55,700,913	55,700,913	64,984,398
Excess gas (m^3)	4,591,884		3,474,070			4,193,010	8,784,893			3,993,573	3,893,855
Annual resource matched power gen capacity (MWe)	4.45	6.68	10.68	15.58	17.81	20.03	22.26	24.48	26.71	28.94	33.39
Installed capacity (MWe)	0.00	10.00	10.00	20.00	20.00	20.00	20.00	30.00	30.00	30.00	35.00
Annual heat supply (GJ)	0	93,103	125,485	217,239	248,273	250,969	250,969	341,376	372,410	376,454	439,196
Methane emission reduction (tCO_2e)	0	193,823	261,237	452,255	516,862	522,475	522,475	710,686	775,294	783,712	914,330
Reduction from grid power offset (tCO_2)	0	60,250	81,205	140,583	160,666	162,410	162,410	220,916	240,999	243,616	284,218
Reduction from displacement of fossil fuel heat (tCO_2)	0	9,087	12,247	21,203	24,231	24,495	24,495	33,318	36,347	36,742	42,866
Project emissions (tCO_2)	0	(25,382)	(34,210)	(59,224)	(67,684)	(68,419)	(68,419)	(93,066)	(101,527)	(102,629)	(119,734)
Emission reduction	0	237,778	237,778	554,816	554,816	554,816	554,816	554,816	951,113	951,113	951,113

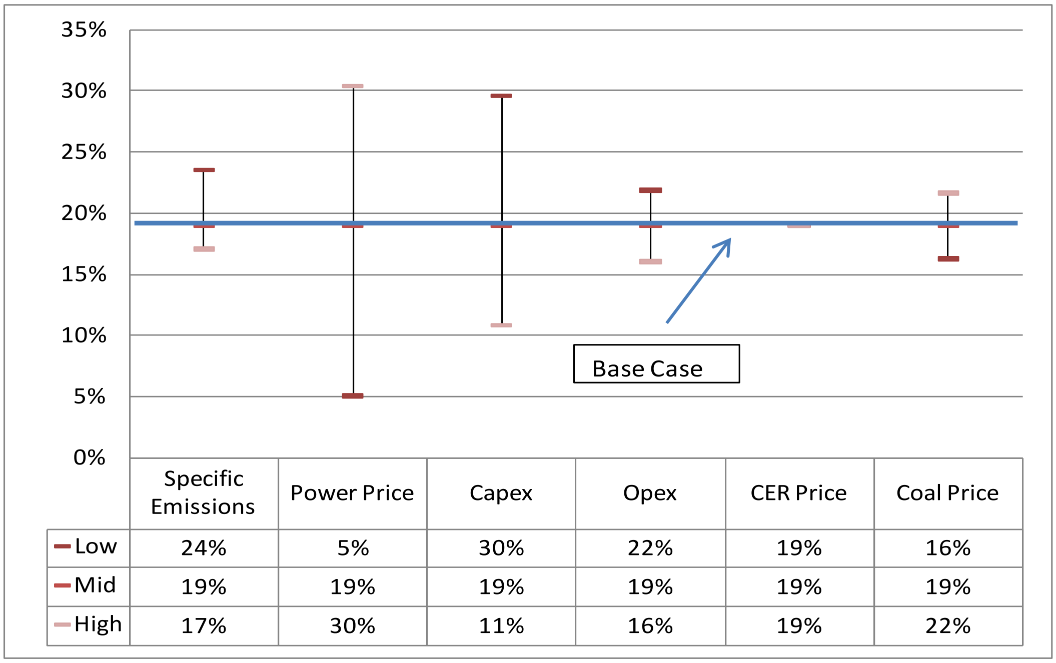
Table A-6: Calculated Thermal Requirement for the Tai Xi Group's Shaft Heating and the Coal Savings Realized by the Proposed Project

Parameter	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Ventilation air flow rate required (m^3/s)	1,111	1,085	1,090	1,085	1,111	1,137	1,164	1,190	1,216	1,243	1,295
Air density (kg/Nm^3)	1.225	1.225	1.225	1.225	1.225	1.225	1.225	1.225	1.225	1.225	1.225
Mass flow rate (kg/s)	1,361	1,329	1,335	1,329	1,361	1,393	1,425	1,458	1,490	1,522	1,587
Ambient temperature (degC)	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
Mine temperature (degC)	5	5	5	5	5	5	5	5	5	5	5
Heating power (MW thermal)	27.22	26.57	26.70	26.57	27.22	27.86	28.51	29.15	29.80	30.45	31.74
Heating time (months)	6	6	6	6	6	6	6	6	6	6	6
Heat energy required (GJ)	429,158	418,974	421,011	418,974	429,158	439,343	449,527	459,711	469,895	480,080	500,448
Installed capacity (MWe)	0	10.0	10.0	20.0	20.0	20.0	20.0	30.0	30.0	30.0	35.0
Used installed capacity (@90%) (MWe)	0.0	6.7	9.0	15.6	17.8	18.0	18.0	24.5	26.7	27.0	31.5
Heat energy from CHP (MWthermal)	0	5.9	8.0	13.8	15.7	15.9	15.9	21.6	23.6	23.9	27.9
Heat energy from CHP (GJ)	0	93,103	125,485	217,239	248,273	250,969	250,969	341,376	372,410	376,454	439,196
Heat demand satisfied	0%	22%	30%	52%	58%	57%	56%	74%	79%	78%	88%
Coal Calorific value (GJ/tonne)	26.34	26.34	26.34	26.34	26.34	26.34	26.34	26.34	26.34	26.34	26.34
Annual coal saving (tonnes)	0	3,535	4,764	8,248	9,426	9,528	9,528	12,960	14,139	14,292	16,674
Annual saving ($)	0	441,831	595,504	1,030,938	1,178,215	1,191,008	1,191,008	1,620,045	1,767,322	1,786,512	2,084,264
Annual savings (million RMB)	**0.00**	**3.00**	**4.05**	**7.01**	**8.01**	**8.10**	**8.10**	**11.01**	**12.01**	**12.14**	**14.17**
Annual savings (USD$)		**470,330**	**627,891**	**1,097,590**	**1,254,370**	**1,255,780**	**1,269,890**	**1,724,700**	**1,881,480**	**1,903,270**	**2,221,530**



	Specific Emissions	Power Price	Capex	Opex	CER Price	Coal Price
▬ Low	74%	64%	88%	74%	57%	70%
▬ Mid	72%	72%	72%	72%	72%	72%
▬ High	79%	80%	60%	70%	85%	73%

Figure A-1: The Sensitivity of Internal Rate of Return to Uncertain Variables Assuming Certified Emission Reductions Revenue



	Specific Emissions	Power Price	Capex	Opex	CER Price	Coal Price
▬ Low	24%	5%	30%	22%	19%	16%
▬ Mid	19%	19%	19%	19%	19%	19%
▬ High	17%	30%	11%	16%	19%	22%

Figure A-2: The Sensitivity of Internal Rate of Return to Uncertain Variables Assuming Certified Emission Reductions: <u>No</u> Revenue

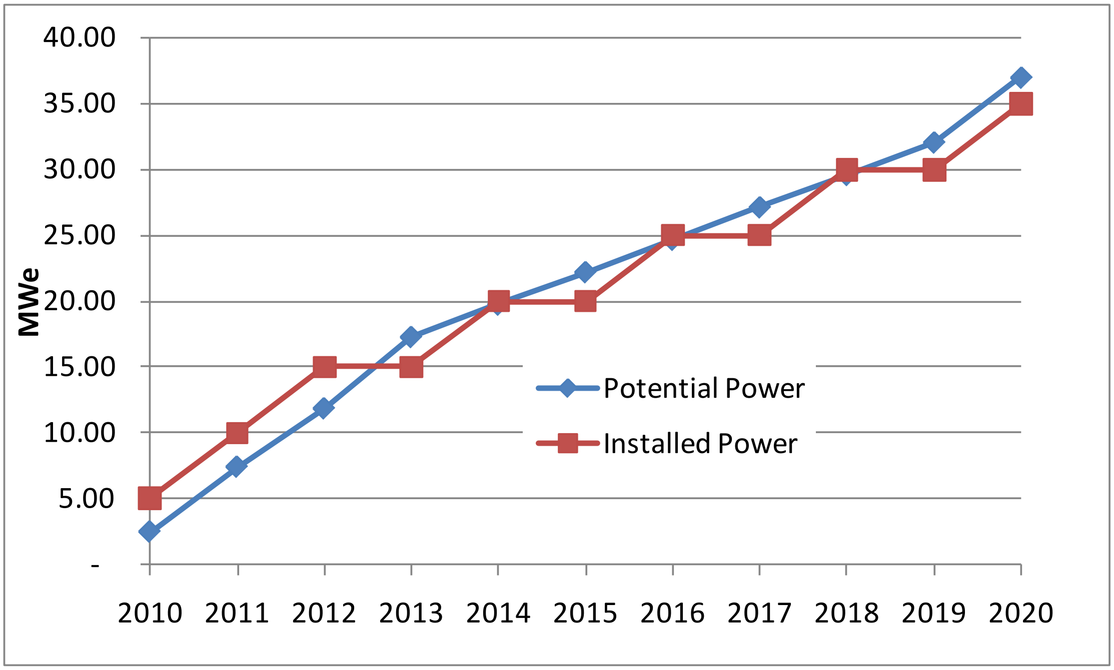


Figure A-3: Base Case Power Generation Forecast (Mid Case Specific Emissions)

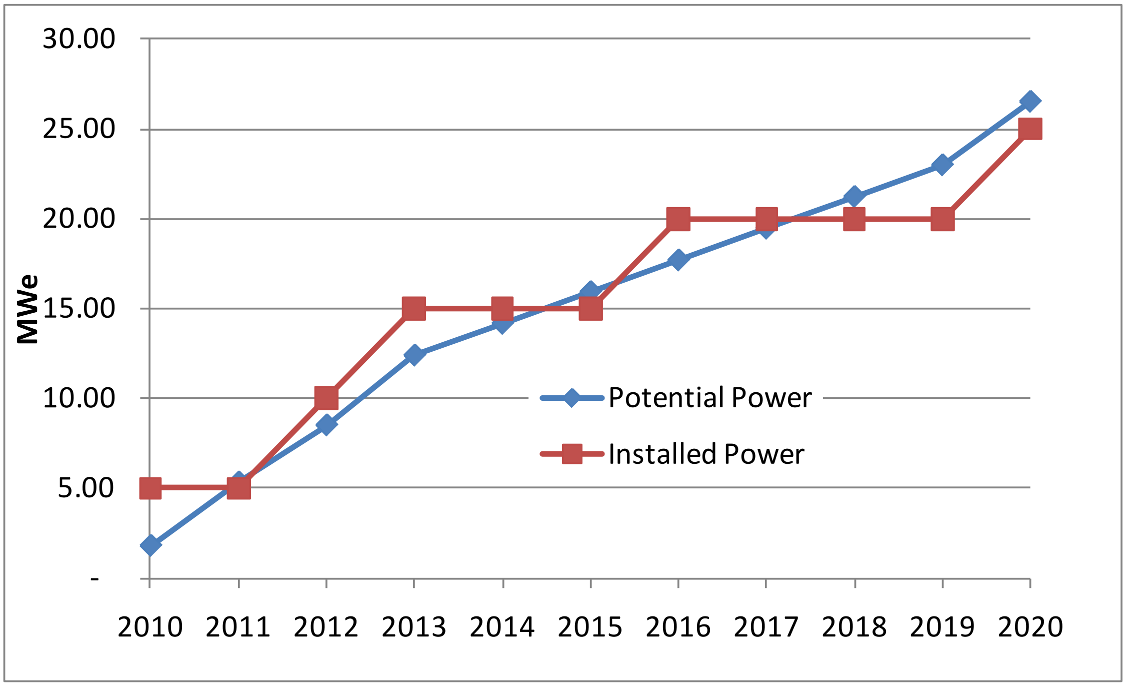


Figure A-4: Low Specific Emissions Power Generation Forecast

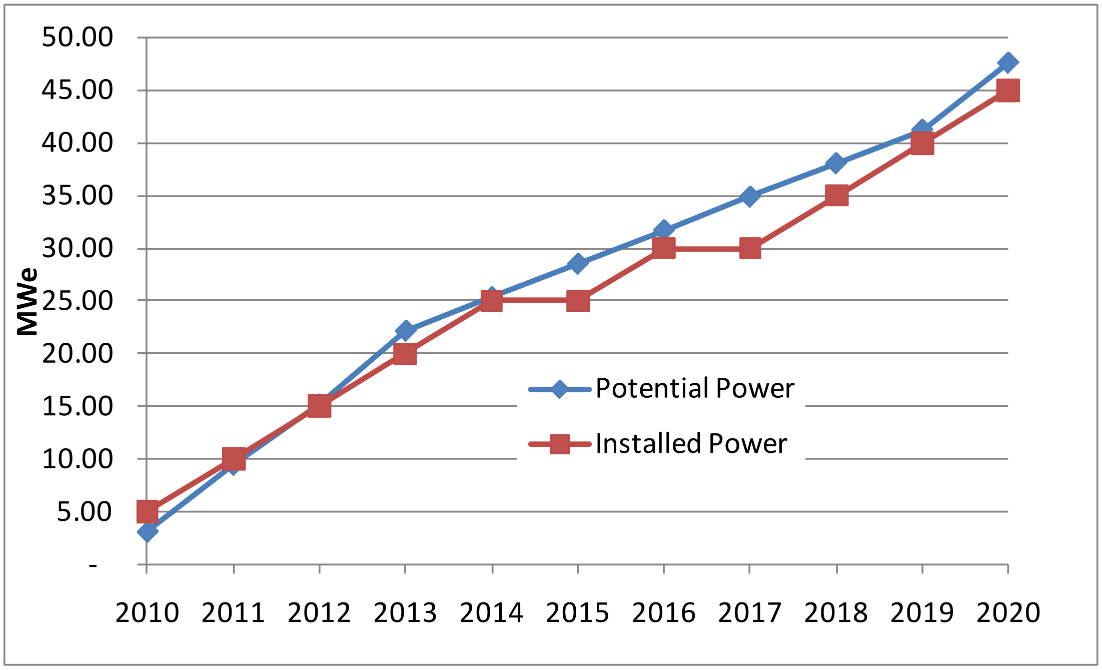


Figure A-5: High Specific Emissions Power Generation Forecast