Zhongling Coal Mine Methane Utilization Pre-feasibility Study Report

Guizhou International Cooperation Center

for Environmental Protection

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Table of Contents

TABLES

FIGURES

1. Executive summary

Funded by the U.S. Environmental Protection Agency (USEPA), Guizhou International Cooperation Center for Environment Protection (GZICCEP) prepared pre-feasibility study of coal mine methane (CMM) utilization for Zhongling Coal Mine, to support the Global Methane Initiative (formerly the Methane to Markets Partnership). The program aims to promote full utilization of CMM resources and to reduce methane emissions by using market-oriented tools.

Zhongling mine is located in the Zhongling Town, Nayong County, Bijie Prefecture, Guizhou Province, China. It covers an area of 500 acres, adjacent to S213 provincial highway. It is 8.5 km away from Nayong power plant, 48 km away from Lanba railway station that connects Guiyang-Kunming railway, Neijiang-Kunming railway, and Zhuliu double railway. It is convenient on transportation and communication. The mine consists mainly of Zhongling and Pingshan mine fields with a screening workshop. With abundant coal reserves and good quality, its mine fields are suitable for large-scale mechanized mining. Its products are mostly high grade anthracite with low ash, low sulfur, super low phosphor, high-calorie, that are ideal raw coal for power generation, chemical industry and metallurgy industry. The mine currently has two fields with designed production capacity of 3 million tonnes/year and designed service life of 76 years. It is one of the largest mines in southwest China.

Zhongling mine has two minefields consisting of three mining areas, using adit mining method. Among them, the Zhongling field (Field 1) has two mining area (Area 11 and 12) with designed production capacity of 1 million tonnes/year each; Pingshan field (Field 2) has an existing mining area (Area 21) with designed production capacity of 1 million tonnes/year. The mine started construction on July 26, 2002 and put into full-scale trial production on June 29, 2006. Its product is raw coal, which is mainly sold to Nayong power plant.

Zhongling mine is one of the earliest coal mines in Guizhou that uses CMM for power generation, and also the first enterprise conducting a CDM (Clean Development Mechanism) project for gas power generation project. Early 2006, the project was already in validation stage. Unfortunately, it has not yet registered as a CDM project in the United Nations till now. Zhongling mine's gas power plant employed low concentration gas power generation technology. This project operates under Liupanshui Qunlian Industry Co., Ltd., which is a subsidiary of the Guizhou Shuicheng Mining Group. Zhongling mine is also a subsidiary mine of Shuicheng Mining Group and its role is to provide CMM and purchase electricity from the power plant. Currently, Zhongling mine had four sets of 500KW generators in Area 11, six sets of 500KW generators in Area 12, and five sets of 500KW generators newly installed in Area 21 in 2010. From statistical data in 2009, the average monthly utilization (100% methane) in Zhongling coal mine for gas power generation was up to 469,900 standard cubic meters. But the monthly drainage was 2,294,000 standard cubic meters. As a result, the average utilization rate of CMM was only 20.48%. A large volume of CMM was vented to the atmosphere.

Two options for gas utilization are analyzed in this study: power generation and gas purification for LNG.

About the Zhongling mine

Zhongling mine's holding company is Guizhou Shuicheng Mining (Group) Co., Ltd. Other shareholders are Yanzhou Mining Guizhou Energy and Chemical Industry Co., Ltd, Guizhou Shuicheng Iron & Steel (Group) Co., Ltd and some employees. Guizhou Zhongling Mining Co., Ltd was established on the basis of modern enterprise structure.

Being former Shuicheng Mining Administration, Guizhou Shuicheng Mining (Group) Co., Ltd was a subsidiary company of former Ministry of Coal. It was established in 1964 and begun to produce coal in 1970. In 1998, it was decentralized to be managed by Guizhou province, and afterwards transformed to be Guizhou Shuicheng Mining (Group) Co., Ltd in 2001 under the supervision of Guizhou Supervision and Management Commission for State Assets.

Yanzhou Mining Guizhou Nenghua Co., Ltd (referred to as "Yanzhou Guihua" in the following) is a 100% subsidiary established by Yanzhou Mining Group in 2002 in Guizhou after it participated in a wave of building large scale coal-fired power plants and supplementary coal mines. In July 2010, Yanzhou Mining Group introduced China Coal mines (Overseas) Group Limited, becoming the strategic investors of Yanzhou Mining Guihua Co., Ltd.

From completion of construction in 2006 to now, Zhongling mine has not yet reached its designed capacity. It is expected to reach its production capacity (3 m t/a) in 2015. Due to damages in one of its main roadways from strata pressures, Zhongling mine produced less than 1 million tonnes of coal in 2010, which yielded very limited economic returns. It is unlikely at this time Zhongling mine will independently develop a CMM utilization project due to financial constraints. Instead, investors are welcomed to co-develop the existing gas resources. Zhongling mine's role will be more on the gas supply end while investors on the capital and technology end.

Geological conditions and resources exploration of Zhongling mine

Overall topography of Zhongling mine is ridged-mountain with medium to high mountain terrain sloping from east to west. It has complex social and environmental conditions with strong disturbance from human activities. Many old coal pits clustered among shallow coal seams and damaged coal seams to different extents. Complexity of its geological and environmental conditions is classified as Grade 1 with frequently-occurred geological hazards.

Zhongling mine has abundant coal reserve with 710.43 million tonnes of geological reserve and 316.47 million tonnes of minable reserve. Field 1 has total minable reserve of 219.86 million tonnes and Field 2 has total minable reserve of 96.61 million tonnes.

The workable seams in Zhongling mine are gassy coal seams with average methane content of 12.54 m^3/t. According to geological reports for Zhongling and Pingshan minefield, for Field 1 the maximum methane content is 19.17 m^3/t at #8 coal seam, the minimum methane content is 10.54 m^3/t at No. 3 coal seam; for Field 2 (+1675 m above), the minimum methane content is 9.00 m^3/t at #7 coal seam, the maximum methane content is 12.00 m^3/t at #8 coal seam. Based on Zhongling mine's geological coal reserve (710.43 million t) and average methane content (12.54 m^3/t), it is estimated that its geological methane reserves is 8.91 billion m^3.

Drainage and utilization of CMM

Based on the weekly CMM drainage statistics in 2010 provided by Zhongling mine, Table 1 compares the actual amount of CMM drainage and the planned drainage amount.

Table 1: Gas drainage in 2010 by areas (averaging in 52 weeks)

Site	Content (%)	Amount of mixture (m^3/min)	Pure amount (m^3/min)	Monthly pure amount (m^3)	Annual pure amount (m^3)	Planned monthly pure amount (m^3)
Average on high pressure pipes in Area 11	10.84	92.59	7.54	339,245	3,962,382	390,000
Average on low pressure pipes in Area 11	0.00	0.00	0.00	-	-	780,000
Total in Area 11			**7.54**	**339,245**	**3,962,382**	**1,170,000**
Average on high pressure pipes in Area 12	17.25	101.78	17.04	766,907	8,957,474	475,000
Average on low pressure pipes in Area 12	10.20	149.18	15.85	713,126	8,329,308	860,000
Total in Area 12			**32.89**	**1,480,033**	**17,286,782**	**1,335,000**
Average on high pressure pipes	9.43	48.91	4.68	210,469	2,458,284	430,000

in Area 21						
Average on low pressure pipes in Area 21	8.22	167.67	14.13	635,653	7,424,431	820,000
Total in Area 21			**18.80**	**846,123**	**9,882,715**	**1,250,000**
Total					**31,131,879**	**45,060,000**

Table 1 shows that the actual amount of CMM drainage was 69% of the planned amount in Zhongling mine. Coal production in Zhongling mine was just a third of its designed capacity, nearly 1 million tonnes in 2010, thus reasonably resulting in less drainage than planned. It could be assumed from the table that actual amount of gas drainage might be much more than planned when its coal production reaches 3 million tonnes a year.

Low and unstable methane concentration of gas drained also increases the difficulty of gas utilization. See figure 1 for the methane concentration change over 2010.

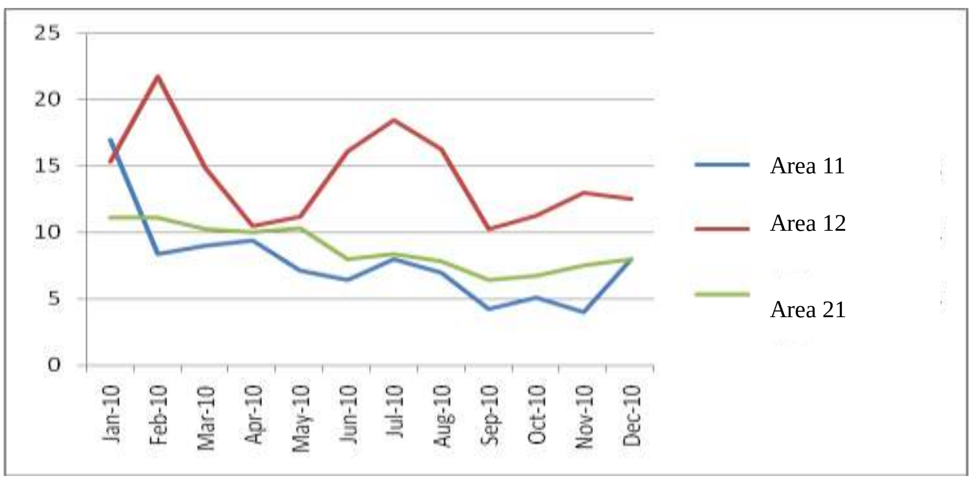

Figure 1: Comparison on methane concentration in Area 11, 12 and 21 in 2010

According to analysis of methane concentrations and flow at the underground drainage points, we believe that coal mines can take appropriate measures to improve and maintain gas drainage system, which could greatly improve gas drainage efficiency and quality.

Currently, Zhongling mine has established gas power stations in three mining areas respectively. They all use low concentration CMM for power generation. There are four units (500 KW) installed in the Area 11. However, due drainage issues in this area, there has been inconsistent gas supply for power generation. Six units (500 KW) are installed in Area 12 and are operating. Five units (500 KW) are installed in Area 21 and are also generating power.

Average rate of CMM utilization in Zhongling mine is only 20.48%. There is great potential to utilize existing CMM, especially at Area 12 where a large amount of CMM is available for use.

Guizhou Coal Market Overview

From 2000 to 2010, raw coal production of Guizhou province increased from 30.25 million tonnes to 150 million tonnes. But it still could not meet the demand of coal (especially coal for power generation) from Guizhou province and neighboring provinces. In 2009, Guizhou's coal consumption totaled 131 million tonnes, of which the largest share was from the power generation industry, amounting to 35.5%. It is expected that increasing coal-fired power generation and emerging coal-to-chemical industries in Guizhou will have stronger demand for coal in the near future.

Zhongling mine mainly supplies coal to Nayong No.1 Power Plant in Nayong County. Built in 2004, the power plant is 8.5 km from Zhongling mine with installed capacity of 1.2 million kilowatts (4 x 300MW) and annual anthracite consumption of 3 million tonnes. Following No.1 power plant, Nayong No.2 Power Plant was completed in 2006. It is only 9 km way from No.1 power plant and has same installed capacity (4 x 300MW) and annual coal consumption. Zhongling mine is the matching coal mine for the so-called "large coal production guarantees large power plants" under the project of "West to East Electricity Transmission". Currently coal is transported by truck to the plants. The Nayong Power Plant is now constructing a coal belt transport system, which is planned to be completed by the end of 2011 and be able to transport coal directly from Zhongling mine to Nayong No.1 Power Plant.

In terms of demands from local power plants, there is no problem for Zhongling mine to sell its coal. The only factor is the price. Currently, the price of coal sold from Zhongling mine to Nayong power plant is stable at about 300 Yuan per tonne. The price is very low for the mine. But it is difficult for the mine to get a satisfactory price since coal pricing for power generation usually subjects to local government's regulation. If coal from Zhongling mine is to be sold outside Nayong County, the local government is to add 100-200 Yuan for each tonne of coal. In this way, Zhongling mine has almost no choice to sell the coal to the nearby power plants. As a result, Zhongling mine would continue to produce and supply coal to the power plants as long as they continue to generate electricity.

Gas Market

Town gas development in Guizhou Province has obviously lagged behind the national average. In 2010, gas accounted for less than 1.0% of total energy consumption in Guizhou, which was far lower than the national average of 3.8%. Currently, the main gas users in Guizhou include urban residential, commercial and public buildings, industrial users, and vehicles.

According to Guizhou Gas Group's plan, natural gas is to be an important source of Guizhou's gas supply, which will come from the "China-Myanmar Oil and Gas Long-distance transportation pipeline" (expected to supply gas to Guizhou in 2013) and "Zhongwei - Guiyang gas transportation pipeline" (expected to supply gas to Guizhou in 2012). It is expected that in 2015, natural gas supply from the long-distance pipelines will reach 1.75 billion cubic meters. In addition, Guizhou Natural Gas Company, Petro China and other enterprises in Guizhou will supply liquefied natural gas (LNG) of about 376 million cubic meters per year, and compressed natural gas (CNG) of about 11 million cubic meters per year. Other gas sources include coking gas and liquefied petroleum gas (LPG).

It is expected that in 2015, total gas supply for Guizhou will be only 2.137 billion cubic meters, while gas demand of Guizhou is expected to be 6.538 billion cubic meters, resulting in a huge gap between supply and demand. If coal mine methane can be purified to make CNG/LNG, it could be an important supplement to natural gas supply in certain areas. If the price is competitive, Guizhou itself will become a huge market.

Electricity Market

By the end of 2010, Guizhou Power Grid has 27.316 million kilowatts of in-pool installed capacity, of which hydropower's installed capacity is 10.176 million kilowatts, accounting for 37% of total installed capacity. The thermal power's installed capacity is 17.14 million kilowatts, accounting for 63% of total installed capacity. The electricity share of Guizhou's CMM power generation is too little and can be negligible. For coal mines, there is only one choice for selling surplus electricity to the power grid besides its captive consumption. The price for power to feed-in electricity from the gas power plant is the key factor to determine the capacity of the gas power plant.

If it is implemented in accordance with China's policies that encourage gas power generation, the economic benefit of a gas power plant would be substantially enough to motivate coal mines to generate electricity by using CMM. But regrettably, only one gas power plant in Guizhou (Hongguo coal mine gas power plant in Panxian County) is so far known to obtain approval of the electricity grid price from the Guizhou Pricing Bureau, at the price of 0.517 Yuan/kWh. The remaining gas power plants were originally designed only for captive electricity consumption of coal mines, without considering selling electricity to the grid. This has resulted in a large amount of surplus CMM not to be fully utilized. The main reasons are described as follows:

- The National Development and Reform Commission (NDRC) stated that the price difference, 0.25 Yuan/kWh over the benchmark grid price for local coal-fired power generation unit with desulfurization facility, can be covered by raising the provincial power grid's sale price where CMM power plant locates. However, Guizhou has not yet formulated any measures with price subsidies while a surcharge of renewable energy on the sale price has been paid to the state. Currently, the inverted difference between CMM power generation price and sale price is paid by the grid company. This obviously is not a sustainable option and will negatively affect the willingness of the power grid company to feed in CMM power.

- Power grid connection for CMM power generation needs to be approved by the Development and Reform Commission, the Power Regulatory Office, the Planning Bureau, Price Bureau, Environmental Protection Bureau, Land and Resources Bureau, Power Supply Bureau and other authorities. This complicated approval process creates a psychological barrier for coal mine owners.
- At present, there are no comprehensive CMM utilization plans for the whole province and individual coal mines. The existing CMM power plants are all built by coal mines themselves without integrated involvement of local authorities. Especially for local small coal mines, despite some having desire to invest, most of them failed to undertake CMM power generation and grid connection due to less understanding of CMM power generation and their own CMM conditions.
- Some of the CMM power plants failed to go through normal approval procedures and did not comply with national procedures for infrastructure construction, including feasibility study, government approval, application of power grid connection, signing agreement to connect power grid, design and review for power grid access, eligible construction, inspection and acceptance. This made it difficult for the power grid to coordinate with actual production and operation of the plants, thus resulting in delay or even failure of grid connection of CMM power generation.
- Subject to limited total available gas volumes and means of drainage, as well as unstable methane concentration, power generators of some power plants do not work stably with frequent starts and stops. This poor operational reliability imposes a potential hazard to coal production safety and stable grid operation, which makes it difficult for the power grid to conduct normal operation and dispatch.

CMM end-use options and analysis

There are no common criteria for assessing how to use CMM, but it should consider not only chemical and physical characteristics like methane concentration and stability of drained gas, but also socio-economic and environment impact on the utilization methods.

It is generally believed in the international community that the low concentration gas with methane content below 30% is not safe and reliable to use. While in China, more than 60% of CMM is of low-concentration with methane content below 25%. The low-concentration gas power generation technology developed in China has been adopted by a growing number of coal mines. The Chinese government has also released a set of safety standards for low-concentration CMM transportation and power generation. In essence, low concentration CMM for power generation has been recognized as one of the utilization methods in China.

Gas use patterns can be classified according to end-use, processing means, distribution means and applicable concentrations. Considering the latter three criteria of classification, the following patterns are either being used or currently under development:

1. Deliver to gas pipeline network (high concentration)
2. Power generation (high and low concentrations)
3. Gas compression, liquefaction (high concentration; low concentrations CMM is also applicable in combined with approach 4)
4. Gas concentration, purification (low concentration, usually above 30%)
   a) PSA (pressure swing adsorption) purification
   b) Molecular sieve adsorption purification
   c) Direct cryogenic separation and purification
   d) Cryogenic methane recovery after catalytic deoxygenation

For different utilization methods, the applicable concentration scope and best concentration range are different. This is the first thing to consider in assessing the technical feasibility of different gas utilization options. In addition, it is necessary to develop a comprehensive evaluation criterion in combination of the purpose of gas utilization. There are three main purposes in extracting and using coal mine methane: to promote safety in coal production, to access new energy, and to reduce greenhouse gas emissions. Therefore, a reasonable evaluation criterion should reflect the progress achieved for the above purposes in the implementation process of gas utilization options. To this end, the project intends to conduct comprehensive assessments to different gas utilization options regarding three aspects including financial benefits, social benefits, emission reduction and environmental benefits, taking into account the obstacles to the project implementation process and operational risk.

The shortlisted options for Zhongling mine are recommended and compared by merits. The options listed are consistent with national industry policies, and are supported by relevant national favorable policies, without any banned barriers in policy or rule.

Based on option comparison and actual situation of Zhongling mine, two options, which are viable for Zhongling mine to select, are shortlisted as CMM power generation and CMM processing for LNG.

Power generation

Methane concentration at Area 11 is less than 10% half of time in 2010. For low methane concentration power generators, the lowest inlet methane concentration is 7-9%. That means half of drained gas cannot meet with inlet requirement. In addition, due to abnormal drainage, there was only 28% of CMM drained compared with the planned volume in 2010. The drainage situation in 2011 is largely uncertain. It is suggested for Area 11 not to expand the power generator temporarily.

Although the actual gas drainage volume at Area 21 is closer to planned drainage volume (66%) compared with that of Area 11, the average methane concentration at Area 21 in 2010 was lower than that at Area 11. Most of methane concentration does not meet with the inlet requirement, so it is also suggested for Area 21 not to expand the power generation capacity.

Methane concentration at Area 12 was stable at 10% or above in 2010, with large amount of usable CMM being emitted. It is suggested for Area 12 to expand the power generation on the basis of its volume balance. Field investigation showed that annual operation hours of the existing domestic generators were less than 5,000 hours. There is surplus gas for expansion. The power generation capacity expansion at Area 12 is suggested to be 2,000 KW, including four sets of 500 KW generator, which could also be standby for existing generators in case of insufficient gas supply for short time. Assuming that annual operation hours are 5500 and gas consumption is 0.384Nm^3/kWh, it could generate 11 million kWh electricity each year. A surplus of 9.86 million kWh could be sold to grid after deducting the captive consumption. This will reduce methane emission by 4.224 million m^3 per year.

Financial analysis of the pre-feasibility report shows that the financial profitability of power generation is poor with 6.04% of IRR (after tax) less than the benchmark rate of 7.5%, NPV (after tax) negative, investment return period (after tax) is 8.53 years, and total rate of return on investment and net capital profitability are 4.66% and 6.99% respectively. In addition, it also shows that power generation has poor ability of repaying debts and poor financial viability, so the power generation is not recommended from financial perspective.

Although the operational risks are controllable, analysis of the financial and operational risks shows that the financial anti-risk capability of power generation is unsatisfactory. Using the break-even analysis as an example, the BEP is 99.23% if calculating from data in the year when reaching its capacity, and is 79.23% if calculating from data in the year (the eighth year) when paying off the loans for construction investment.

In addition there is significant uncertainty of power to grid that would greatly restrict the scale of gas drainage and use, so power generation is not recommended.

CMM for LNG

This option is to purify and liquefy the drained CMM on-site for LNG production, then transport the LNG by tanker to remote downstream end users. This option is recommended based on the fact that the Zhongling mine is too far to access to gas pipelines but relatively easy for transportation, with advantages of reliable and low-risk long haul transport, high-efficiency storage and strong adaptation of LNG. In addition, the cold air released from on-site CMM liquefaction can be recovered for use, and low temperature liquefaction can also produce usable by-products through separation process in safe production and use. CMM preparation for CNG is not considered as the Zhongling mine is more than 200 km from key CNG markets e.g. Guiyang and Zunyi, with high cost of transportation.

The gas source is mainly the surplus gas from Area 12. As the pump stations at Area 11 and 12 are close, when it is available (for example drainage volume and concentration remarkably increase to meet with requirement of transportation), the drained CMM from Area 11 could also be transported to Area 12 for utilization. As Area 21 is far from the pump station of Area 12 and transport is too complicated, the surplus gas from Area 21 could be used for on-site power generation instead of transporting to Area 12 for centralized utilization.

Common CMM purification techniques require methane concentration at more than 30%. Through communication with the engineers, Zhongling mine is able to provide CMM with methane concentration of about 25%, so the inlet methane concentration is set at 25% in the option[1]. As low concentration power generators are getting common, most coal mines have no motivation to increase gas concentration for power generation. Only when CMM is purified to produce CNG/LNG with value added up, coal mines would be driven to increase concentration and volume of drained gas. Methane content in enriched LNG from raw gas will be above 98% and the methane recovery rate for this option will be 95%.

Considering the domestic LNG market and current gas drainage in Zhongling mine, the capacity and annual operation hours of LNG production are set as 11,300t/a and 8,000 hours respectively.

Financial analysis shows that pre-tax and after-tax IRR of this option are 27.0% and 18.3%, both higher than the benchmark rate of 12% for natural gas industries. The NPV is 28.99 million Yuan (after tax at 7.5% discount rate). The static investment return period (including construction period) is 5.51 years. The key indicators show that this option has good financial profitability.

In addition, risk analysis shows that this option is good in anti-financial risk. Sensitivity

[1] Reference, provided by DKT Energy Technology Co. LTD, show that the gas purification system could actually purify gas by more than 5%, but with corresponding degrading economical parameters.

analysis indicates that LNG sales price and LNG production are the most sensitive factors. LNG sales price is unlikely to drop. So the key is to maintain a good supply of CMM as feed gas. The break-even analysis indicates that the effective production is 55.06% of its capacity, where profits would be obtained if production is beyond the break-even point.

Analysis of operational risks also indicates that there are no uncontrollable risks for this option. But there exist risks of collaboration, such as negotiation with transport companies for tankers, with public transport companies for constructing gas filling stations and modifying vehicles. Balancing risks and benefits, this option is still recommended.

End-use comparison

Under the prior evaluation criterion, the above two options are compared as follows in terms of financial, social and environmental benefit.

I. Comparative analysis of financial benefits : The power generation option has a negative financial net present value indicating no potential to create profits; while the same parameter for LNG is much higher than zero indicating better profitability. In terms of financial internal rate of return, LNG has better profitability than power generation. In addition, debts repay and financial viability of LNG is much better than power generation. Power generation is more competitive than LNG in terms of less initial investment and less requirement for repaying debts, as well as lower financing costs.

Table 2 shows impacts of key costs and income changes on overall financial benefits:

Table 2: Investment benefits comparison of power generation and LNG production

Indicator	Unit	Power generation	LNG
Service life	Year	10	10
Estimated fixed asset investment	Ten thousand Yuan	1805	5835
Working capital	Ten thousand Yuan	26	150
Break-even point	%，yearly average	99.23%*	55.06%
Financial IRR of investment (after income tax)	%	6.04	18.3
Financial NPV of investment (after income tax)	Ten thousand Yuan	-113	2899

Payback period of investment (after income tax)	Years	8.53	5.51
Financial IRR of investment (before income tax)	%	7.79	27.0
Financial NPV of investment (before income tax)	Ten thousand Yuan	23	5539
Payback period of investment (before income tax)	Years	7.92	4.4
* Calculation is made based on relevant data of the year when production reaches designed capacity.			

<u>II. Comparative analysis of risks:</u> anti-financial risk of the two options are analysed through sensitivity analysis, with focus on four common operational factors (relatively comparable) which could influence the IRR. When their values change within -20% ~ +20%, the influences on the overall economical sustainability and stability are presented in Table 3.

Table 3: Financial sensitivity analysis of the options

Variables	Power generation		LNG	
	Factors (Power generation)	Financial internal rate of return on investment after income tax (%)		Factors (LNG)
+20	Electricity sales price	11.94	28.4	LNG sales price
+10		9.06	23.5	
-10		2.78	12.8	
-20		-1.09	6.7	
+20	Electricity production	10.50	28.4	LNG production
+10		8.31	23.0	
-10		3.63	13.3	
-20		1.06	7.8	
+20	CMM purchase price	4.94	17.4	CMM purchase price
+10		5.48	17.8	
-10		6.55	18.7	
-20		7.06	19.2	
+20	investment	2.72	13.6	investment
+10		4.25	15.8	
-10		8.09	21.3	
-20		10.56	24.9	

Results of comparing the operational risks are summarized in table 4 below:

Table 4: Total number of risk factors and their ratings

Power generation	LNG
Market	
High (1), medium (1)	Low (2), uncertain (2)
Gas supply	
Low (2), high (1)	High (1), low (2)
Technical	
Low (2)	Medium (2)
Environmental and safety	
Low (1), unknown (1)	Low (3)
Financing	
Low (1)	Unknown (2)
Policy	
Medium (1)	Low (1)
Collaboration	
Low (3)	Low (1), unknown (2)

III. Comparative analysis of emission reduction benefits:

- Power generation: In current project phase, there are four 500KW power generators. Calculated according to 5500 working hours per year and methane consumption rate of 0.384Nm^3/kWh, the annual electricity output can reach 9.856 million kWh, reducing methane emission 4.224 million m^3, which is equivalent to 60,319 tonnes of CO_2 emission.

- LNG： Emission reduction is calculated in the table below:

Formula	Equivalent CO2 emission reduction = CMM emission amount ×0.01428	
Item & coefficient	Explanation	Result
1.CO_2 equivalent (Tonne)	CMM consumed for producing LNG is converted into annual emission reduction.	218,427
2.CMM volume (m^3)	Pure methane consumption a year for producing LNG.	15,290,000
*Assuming that it has an annual capacity of processing 64 million Nm^3 of CMM (25% methane concentration) and operating time of 8000 hours, if the methane recovery rate is 95.6%, the result would be 64 million Nm^3×25%×95.6%=15.29 million Nm^3.		

IV. Comparison of socio-economic benefits: The socio-economic benefits of both options are obvious: their implementation meet with the national policies of developing circular economy, energy conservation and cascade utilization as well as cleaner production; and they can promote safe coal mining and integrated coal utilization by 'enhancing drainage for use' and 'enhancing mining safety by drainage', as well as can improve local employment. Comparatively, LNG has better socio-economic benefits.

For a long term, LNG has more remarkable overall socio-economic benefits, such as enhancing national energy security through energy substitution, increasing added value of coal industry by extending industry chain, and promoting energy saving and emission reduction by enterprises and communities through trans-regional and cross-sector demonstration and pioneering.

Conclusions

Zhongling mine currently produces 1 million tonnes of coal a year. However, it drains more than 30 million m^3 of methane a year, almost 70% of expected gas drainage volume for an annual coal production of 3 million tonnes. When Zhongling mine reaches its designed capacity in 2015, we expect a significant increase of drained gas. With existing CMM, there is only 20% utilized through low concentration power generation. Constrained to sell electricity to the grid, the majority of existing CMM calls for an alternative utilization option. Through our pre-feasibility study, we recommend a full scale feasibility study to look at CMM-to-LNG option regarding existing and future gas resources in Zhongling mine.

Based on the above comparative analysis, additional preliminary conclusions are listed below:

1. Both options presented for the Zhongling mine - power generation and LNG – improve coal mine safety and reduce methane emissions to the atmosphere. But in terms of economic and technical evaluation, the power generation option is not feasible due to poor performance in profitability, debts repayment, financial viability and anti-financial risks. In addition, there exist huge operational risks for power generation onto the grid. In contrast, despite a high initial investment, high financing costs and long payback period of investment, the long-term expected profit and investment return of LNG are both higher than that of power generation. From both the medium and long term perspectives, LNG has better overall economic and environmental benefits than the power generation option, with a promising development future.

2. The biggest operational risks of LNG implementation include negotiation with transport companies on transportation by tanker, with urban public transport companies on gas filling station construction and vehicle modification, as well as

project financing. It is strongly recommended that the project developer starts consultation with stakeholders as early as possible and formulate measures for reducing collaboration risk.

3. Having built and managed CMM power generation plants, the Zhongling mine is familiar with CMM power generation techniques. It is easy to habitually follow those adept techniques. However, the low concentration power generation is unlikely the best option for CMM utilization due to its low efficiency of energy conversion and potentially unsafe working conditions. LNG produced from CMM is a technological innovation for Zhongling mine and has better market potential. Despite complexity of the technology and higher investment, CMM to LNG production seems worthy of investment with better returns.

4. The primary purpose of coal mine gas drainage and utilization is to promote coal mining safety. Guizhou is poor in oil and gas sources, but it has an increasing demand for natural gas. While it is difficult to provide CMM power generation to the grid, CMM purification for LNG could become an extension of the coal mining industry in Guizhou with huge market potential. It this way, the motivation of draining more and better quality CMM for LNG would be much higher than for power generation, thus improving mining safety significantly. In this regard, the option of CMM for LNG should be actively promoted in Guizhou.

5. Compared with gasoline, diesel and LPG vehicles, CNG vehicles have irreplaceable advantages in terms of environmental protection, economy or safety, and are also a more mature technology than LNG vehicles. However, LNG is much better in storage and refueling is faster than CNG vehicles. LNG is likely to compete with or even replace CNG in the future. Upon the provincial natural gas utilization plan ("gas from Sichuan into Guizhou," "gas from Myanmar into Guizhou"), development of a natural gas based vehicle industry in Guizhou is likely to unfold as follows: In the early stage, vehicle retrofit techniques for CNG-gasoline dual-fuel system are introduced to launch a natural gas vehicle market, and gas fueling stations are gradually constructed. The retrofit mainly focuses on gasoline buses and taxis (e.g. Zunyi City). In the mid-term, CNG and LNG single fuel vehicles are introduced directly, such as in the Guiyang bus system. In the long term, with the introduction of LNG and the maturity of LNG technology, LNG as a fuel will be introduced to long distance buses (inter-city) and trucks to transport coal. To hold an invincible position in the increasingly competitive vehicle fuel market, Zhongling mine should pay more attention to the mid and long term market trends of switching oil to gas by public transportation in Guizhou.

6. To make good use of the drained CMM of Zhongling mine, both the methane concentration and volume have to be increased. This will not only improve mining safety but will also lay the foundation for optimizing gas use. With this foundation,

surplus gas from Area 12 can be used to produce LNG. If the methane concentration of surplus gas at Area 11 is able to meet transport requirements (>30%), it could be transported via pipe to LNG production system at Area 12. If it is difficult to transport, the gas could be used for on-site power generation to provide electricity for LNG production. As Area 21 is too far away from Area 11 and 12, its surplus gas is recommended for on-site power generation.

2. Project outline

2.1. Background of pre-feasibility study

The report is prepared by experts from GZICCEP to support the "Global Methane Initiative", which aims to promote methane reduction through marketing and using methane as clean energy. As a founding member country of this program, China has actively formulated relevant policies in recent years on promoting comprehensive utilization of CMM which is the major methane emission source. This project, funded by the US EPA, aims to promote CMM utilization and mining safety for two case mines in Guizhou, by preparing the pre-feasibility study reports on CMM utilization. Zhongling Coal mine is one of the two case mines.

2.2. Location and general description of the Case study

Zhongling Mine is located in southwest of Nayong County, Bijie Prefecture, Guizhou Province. It is within the jurisdiction of Zhongling Town which is 16 Km eastward away from the county. The county is 109Km, 76Km, 93Km and 71Km respectively away from Bijie, Dafang, Zhijin and Liupanshui. Zhongling mine is very close to the refurbishing Na-Shui Grade 2 road of S213 provincial highway, 8.5Km westward to Nayong Power Plant and 48Km to Lanba railway station.

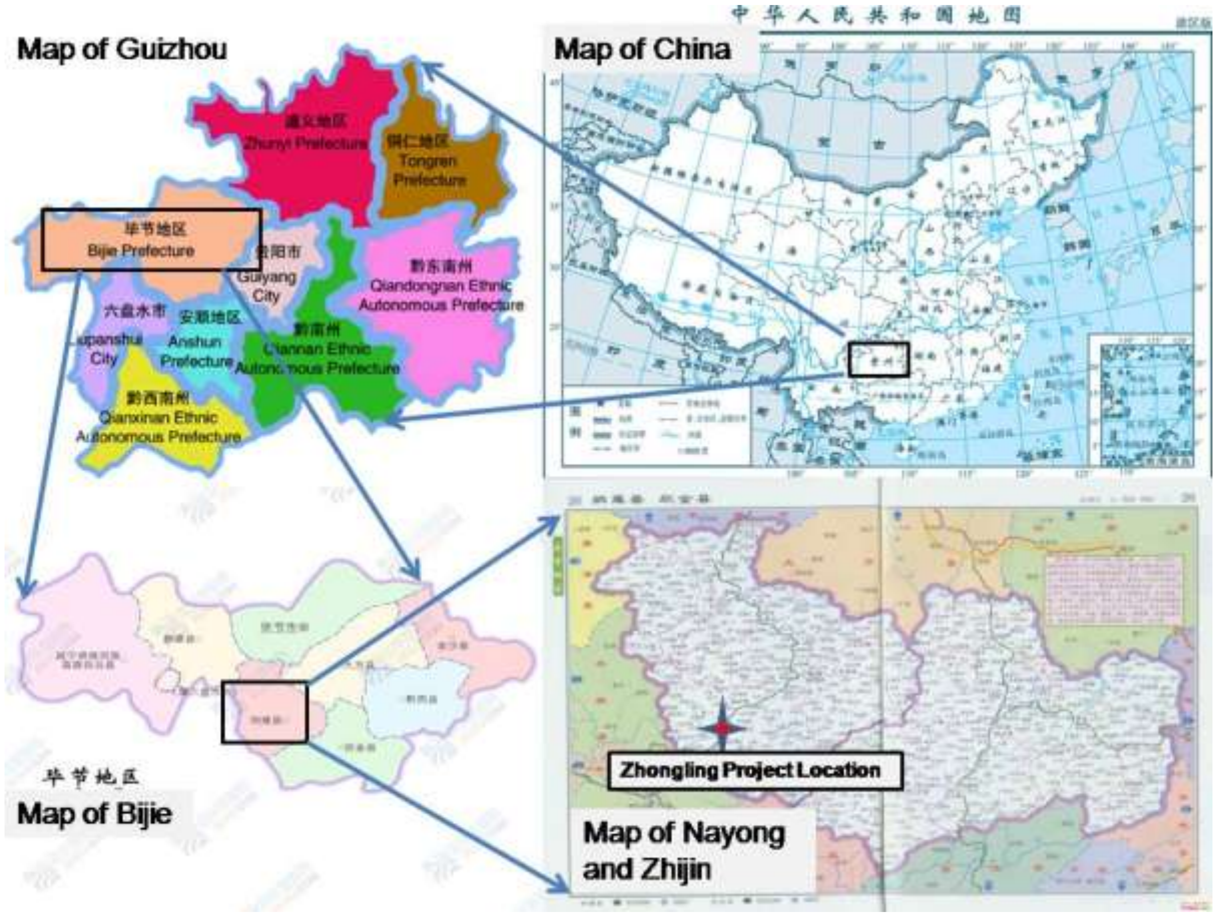

Figure 2: Location of Zhongling mine

With designed annual production capacity of 3 million tonnes, service period of 51 years and total area of 22 km^2, Zhongling mine has two mine fields and three mining areas, using adit mining method. Zhongling mine field (Field 1) has two mining areas (Area 11 and 12), each has a designed annual coal production capacity of 1 million tonnes; and Pingshan mine field (Field 2) has one mining area (Area 21) with designed annual coal production capacity of 1 million tonnes. Construction of the coal mine begun in 2002 and trial production was in 2006, major product is raw coal which is mainly provided for Nayong Power Plant.

Zhongling mine is one of the earliest coal mines in Guizhou that uses CMM for power generation, and also the first enterprise conducting a CDM (Clean Development Mechanism) project for gas power generation project. Early 2006, the project was already in validation stage. Unfortunately, it has not yet registered as a CDM project in the United Nations till now. Zhongling mine's gas power plant employed low concentration gas power generation technology. This project operates under Liupanshui Qunlian Industry Co., Ltd., which is a subsidiary of the Guizhou Shuicheng Mining Group. Zhongling mine is also a subsidiary mine of Shuicheng Mining Group and its role is to provide CMM and purchase electricity from the power plant. Currently, Zhongling mine had four sets of 500KW generators in Area 11, six sets of 500KW generators in Area 12, and five sets of 500KW generators newly installed in Area 21 in 2010. From statistical data in 2009, the average monthly utilization (100% methane) in Zhongling coal mine for gas power generation was up to 469,900 standard cubic meters. But the monthly drainage was 2,294,000 standard cubic meters. As a result, the average utilization rate of CMM was only 20.48%. A large volume of CMM was vented to the atmosphere.

2.3. Profile and financial status of Zhongling mine

Zhongling mine's holding company is Guizhou Shuicheng Mining (Group) Co., Ltd. Other shareholders are Yanzhou Mining Guizhou Energy and Chemical Industry Co., Ltd, Guizhou Shuicheng Iron & Steel (Group) Co., Ltd and some employees. Guizhou Zhongling Mining Co., Ltd was established on the basis of modern enterprise structure.

Profiles and information about the two biggest shareholders are described as follows.

2.3.1. Guizhou Shuicheng Mining (Group) Co., Ltd

Being former Shuicheng Mining Administration, it was a subsidiary company of former Ministry of Coal. It was established in 1964 and begun production in 1970. In 1998, it was decentralized to be managed by Guizhou province, and afterwards transformed to be Guizhou Shuicheng Mining (Group) Co., Ltd in 2001 under the supervision of Guizhou Supervision and Management Commission for State Assets. Over the past 40 years, it has been gradually constructed and developed into a large scale comprehensive enterprises group engaging in coal mining and processing, coal chemical, coking, mechanical processing, power generation, construction and building materials, medicine, real estate and logistics.

Its total assets are worth 14.9 billion RMB Yuan, having total employees of 25,000 in which 6600 are professionals and technicians. It owns ten coal mines by far (another two in planning) with total coal production capacity of 11.66 million tonnes per year; four coal washing plants with capacity of 5.8 million tonnes per year. Coal production employs the domestically state of the art fully-mechanized equipment for mining, caving and driving, coal washing employs triple-product pressure-free spinning heavy medium washing process. In 2009, its annual raw coal production was 10.16 million tonnes, and will reach 16 million tonnes by 2012, finally targeting 40 million tonnes. Its total power generation capacity is 38,000KW, consisting of 12,000KW for one gangue power generation, 26,000KW for seven CMM power generators. It is the second biggest state-owned coal mine group in Guizhou.

2.3.2. Yanzhou Mining Group Guizhou Nenghua Co., Ltd

The company was established upon modern enterprise system and has an independent legal entity, with shares absolutely held by Yan Mine Group. As the major investor of Yanzhou Mining Group in Guizhou, it has taken the full advantages of the national strategy of grand western development and national planning for “western electricity to east”, “Guizhou electricity to Guangdong”, as well as sufficiently utilizing abundant coal resources in Guizhou. Its business is not only centered on coal production and coal—power joint production, but also is extend into coal chemical industry, aiming at maximizing project development benefits.

Yanzhou Mining Group, its parent company, is one of the 100 national demonstration companies for establishing modern enterprise system and of the 120 enterprise groups, and also the first coal company in China who issued shares and listed at stock exchanges in New York, Hong Kong and Shanghai. The group has total assets worth 25.2 billion RMB Yuan consisting of 50 wholly-owned subsidiary companies, holdings and joint shares companies, and owned state of the art fully-mechanized top coal mining and caving technologies. In ten years, the group will be developed to the China’s biggest coal production and export base, the world class base for clean coal and coal chemical industry.

From completion of construction in 2006 to now, Zhongling mine has not yet reached its designed capacity. It is expected to reach its production capacity (3 m t/a) in 2015. Due to damages in one of its main roadways from strata pressures, Zhongling mine produced less than 1 million tonnes of coal in 2010, which yielded very limited economic returns. It is unlikely at this time Zhongling mine will independently develop a CMM utilization project due to financial constraints. Instead, investors are welcomed to co-develop the existing gas resources. Zhongling mine’s role will be more on the gas supply end while investors on the capital and technology end.

3. Coal resources and methane drainage in Zhongling mine

3.1. Geological environment[2]

3.1.1. Landform and topography

Zhongling mine's area landforms and topography generally appear in the Ridge Mountains, high and middle landforms, which are higher in the east and lower in the west. Landforms at the junction of Field 1 and Field 2 are lower with higher two wings. Landforms at Field 1, along its coal outbreak, are higher in the east and lower in the west with the highest at Mazhong hill and lowest at Nanxiao River in Heba village. Field 2, Pingshan field, lies higher in the south and lower in the north with the highest at the peak of Nan hill and the lowest at a river dam northwest of Yakoutian. Mountains trend in the similar direction as strata, and valleys mostly lie on the strata's transverse direction. Coal bearing strata are susceptible to weathering, forming reverse slopes. Rushing gullies are well developed and are mostly covered by quaternary loose materials featuring a deep valley and sharp slope.

The terrains cut sharply in the coal mine fields, while soft rock strata are well developed. In Field 2, structural fracture zones are well developed. The lithological characters and geological structures are even more complicated, forming worsening hydrogeological and geotechnical conditions for engineering works. In addition, its surrounding social environment is complicated due to intensive human activities of mining. Densely distributed coal pits in the shallow seams damage coal seams to different extents, with the most damage to the major mining seams, seam 3 and 6. Long-term unregulated coal mining activities resulted in serious environmental problems, such as: seven landslides including one large scale and six small scale, 14 rock avalanches, five uneven ground settlements and ground fissures which caused house wall and foundation cracking or deforming in 180 households (affecting 788 persons), and two small scale valley mudslides. There are 18 solid waste sites, 43 old coal pits, and many underground goafs resulted from 31 previous smaller coal mines. Therefore the complexity of geological environmental conditions was classified as Grade 1 with frequently-occurring geological

[2] Also refer to "Coal mine methane occurrence and outbreak elimination measures in Zhongling minefields" (Deng W.L, et al., China Coal Geology. Vol. 03 200), in addition to pre-feasibility study reports prepared by Hefei Institute of Coal Mine Design and Sichuan Dakete Company.

hazards.

3.1.2. Geological structure

The geological structure in the mining fields is subject to central Guizhou's ancient arch-breaking fold beam in the Yangtze fold belt (level II) above Yangtze – the Huai platform (level I), a relative uplift featuring a diamond-shaped border profile, which formed on the upper Yangtze fold belt for a long time. They stretch either NW-formation or EW-formation as well as NE-formation, a more complex structural form resulting from the interlinkage and overlaying of early and late stages (see Figure 3).

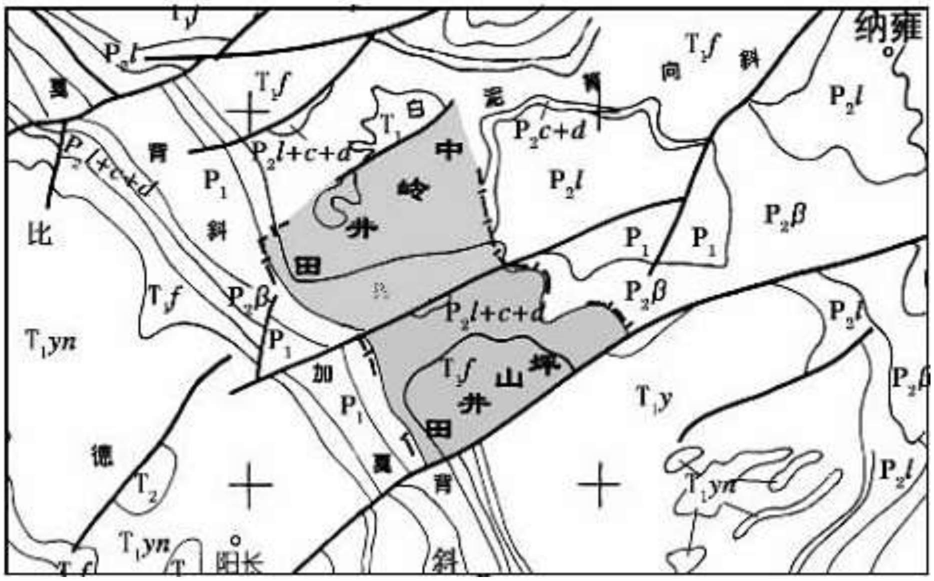

Figure 3: Structural diagram of Zhongling mine fields

Within the fields, except for the upper Permian Emeishan basalt formation being volcano rocks, all others feature sedimentary rock with Permian and Triassic strata widely distributed. The exposed strata include by age: upper Permian Tonge group, Meishan basalt group, Longtan group, Dalong group, Lower Triassic Feixianguan group, Yongning County group and quaternary stratum.

3.1.3. Fold and fault

The structure is formed by two orders. NW-formation was formed first (e.g. Jiaga anticline), while Heba syncline, F12 fault etc. were derived from the NW-formation, and afterwards NE-formation formed, e.g. F1 and F15 faults. The later formations caused damages to the earlier ones. The main formations are NW and NE determining coal seams storage and distribution. Basically shallow strata are more complex with bigger changed strata trends. Most fault drop heights are getting shorter gradually from shallow to deep and eventually disappearing. Dip angles of strata are also getting smaller gradually from shallow to deep.

There are 20 faults found in the Zhongling fields (F1 - F15, F01- F03, F05, F08) with an average of 0.68 faults per squire kilometers. Among them there are four faults with drop height more than 30 meters. The rest of them are less than 30 meters.

As shown in Figure 3, the fields lie on the central NE wing of Jiaga anticline and northward of F1 fault. The stratum forms a dustpan-like shape dipping northward. The trend lines change significantly: the one at the near-east goes toward west and the ones at the west and the east go north-south direction. The stratum slopes northward at dip angle of 20° - 15° in the shallow areas. There are steep areas in the west with dip angle between 43° and 30°. Once it reaches the deeper areas, the angles gradually decrease to 15°, 9°, and then 5°.

3.2. Coal & gas resources and reserves

3.2.1. Coal deposit

The coal bearing strata, being Permian Longtan group, are sea-land crossing stratum with depths of up to 321.27m, consisting of upper, medium and lower segments. There are no coal seams to mine in the medium segment; the distance between the upper and lower segment is 140m; and the distance between adjacent seams in the same segment are 10 - 15m. It is categorized as a coal seam group with close distances between seams. The main seams to be mined are numbered as 1#, 3#, 6# and 8#.

Zhongling mine has abundant coal reserves with 710.43 million tonnes of geological reserve and 316.47 million tonnes of minable reserve. Field 1 has total minable reserves of 219.86 million tonnes and Field 2 has total minable reserves of 96.61 million tonnes.

3.2.2. Coal mine methane resources

3.2.2.1. Reserve analysis

The minable seams are all of high methane concentration with average CMM content at 12.54m^3/t, being treated as high-methane-content coal mine. The geological reports for Zhongling and Pingshan field indicated that the highest gas content is at 8# seam (19.17m^3/t) and the lowest is at 3# seam (10.54m^3/t) in Field 1, and the highest is at 8#

seam (12.00 m^3/t) and the lowest is at 7# seam (9.00m^3/t) in Field 2.

A report on coal mine methane basic parameters measurement and risk assessment for outbreak, prepared by Academy of Coal Sciences and Research Chongqing Branch, shows that the highest content in 3# seam is 12.17m^3/t, and 12.46 m^3/t in 8# seam.

CMM in this mine has the following characteristics:

1. Gas contents: CH_4 76.30% - 99.99%, average at 95.94%; CO_2 max. 17.63%, normally <10%.
2. Gas weathering belts: based on the baseline of 2ml combustible gas in one gram of combustible substances, the belts can be divided into weathering belt in the upper level and gas belt in the lower level. The gas weathering belt is about 60m to surface.
3. Gas content and changes: Gas content in seams - 7.12 - 17.92m^3/t, Permeability coefficient - 0.01 - 2.9m^2/MPa^2.d, and Gas pressure - 0.38 - 2.1MPa.
4. Gas gradient: content increased by 1m^3/t in every 29.59m increased depth.
5. Gas growth rate: content increased by 3.38m^3/t in every 100m increased depth. Gas content of the same borehole increase by depth vertically.

For gas contents in Field 1 and 2, see tables below.

Table 5: Gas contents of main seams in Field 1 （unit:m^3/t）

Seam No.	1	2	3	6	7	8	9	10	28	31	32
+ 1640m or above	9.4	8.3	8.2	11.5	11.1	9.7	10.5	7.2	8.2	8.0	
+ 1640 ~ + 1500	11.0	9.7	8.6	12.2	12.2	12.5	10.2			16.5	10.0
+ 1500 ~ below	11.4	10.8	11.9	13.8	13.3	15.2	10.9				

Table 6: Gas contents of main seams in Field 2（unit: m^3/t）

Seam No.	1	2	3	4	6	7	8
+ 1675m or above	8.5	8.1	9. 5	9.3	8.5	7.2	9.9

Note: no gas data available below +1675m for Field 2

No assessment has been made on coal mine methane resources of the fields so far. Based on Zhongling mine's geological coal reserve (710.43 million t) and average methane content (12.54 m^3/t), it is estimated that its geological methane reserves are 8.91 billion m^3.

3.2.2.2. Gas emission estimation

Relative gas emission in Fields 1 and 2 during the mining period is estimated as follows, based on the relative gas emission of different seams, together with gas emission from advancing in coal roadways and semi-coal rock roadways:

Table 7: Relative gas emission

Field	Altitude	Relative gas emission amount (m^3/t)
Field 1	+ 1640m or above	18.5
	+ 1640 ~ + 1500	23.3
	+ 1500 ~ + 1400	30.0
Field 2	+ 1675m or below	36.0

3.2.2.3. Coal mine methane drainage

As a state-owned large coal mine, Zhongling mine has installed a fairly-standardized coal mine methane draining facility. Three permanent surface coal mine methane pump stations have been installed at ventilating shafts of Areas 11, 12 and 21, centrally draining gas from the mining area. A high and low negative pressure coal mine methane drainage system is equipped for each station. Table 8 below shows the drainage configuration:

Table 8: Gas drainage system configuration by area

Area		Type of vacuum pump	No.	Power (kW)	Diameter of main pipe (mm)	Rated capacity m^3/min	Actual capacity m^3/min	Remarks
Area 11	High pressure	2BEC52	1	250	273	200	160	Two by one standby
		2BE3-420-2BY4	1	200		120	60	
	Low pressure	2BEC52	2	250	630	200	160	Two by one standby
Area 12	High pressure	2BEC42	2	160	377	120	65	Two by one standby
	Low pressure	2BE3-420-2BY4	3	200	630	200	150	Two by one standby
Area 21	High pressure	2BEC42	2	160	377	120	60	Two by one standby
	High pressure	2BE3-420-2BY4	3	250	630	200	140	Two by one standby

The gas drainage of different mining areas in Zhongling mine is planned as follows:

A. Area 11：

- Drain gas from the goaf at the upper corners of the working area (open draining), by using a pump (2BEC52) linked with a 25-inch main pipe and 18-inch branch pipe. The methane content is estimated at about 14% and the volume of mixed gas is about 130m^3/min, while volume of pure methane is about 18m^3/min with a monthly amount of 780,000 m^3.
- Drain gas from pre-mining boreholes in advancing faces, working seams and high-level boreholes (enclosed draining), by using a pump (2BEC52 or 2BEC42) linked with a 12-inch main pipe and 6-inch branch pipe. The methane content is estimated at about 12% and the volume of mixed gas is about 75 m^3/min, while the volume of pure methane is about 9 m^3/min with a monthly amount of 390,000 m^3.

B. Area 12：

- Drain gas from the goaf at the upper corners of the working area (open draining), by using two joint-operation pumps (2BE3-420-2BY4) linked with a 25-inch main pipe and 18-inch branch pipe. The methane content is estimated at about 10%, volume of mixed gas is about 200m^3/min, while the volume of pure methane is about 20m^3/min with a monthly amount of 860,000m^3.
- Drain gas from pre-mining boreholes in advancing faces, working seams and high-level boreholes (enclosed draining), by using a pump (2BEC42) linked with a 14-inch main pipe and 6-inch branch pipe. The methane content is estimated at about 15% and the volume of mixed gas is about 75m^3/min, while the volume of pure methane is about 11m^3/min with a monthly amount of 475,000m^3.

C. Area 21：

- Drain gas from the goaf at the upper corners of the working areas (open draining), by using a pump (2BE3-420-2BY4) linked with 25-inch main pipe and 18-inch branch pipe. The methane content is estimated at about 15% and the volume of mixed gas is about 130m^3/min, while the volume of pure methane is about 19m^3/min with a monthly amount of 820,000m^3.
- Drain gas from pre-mining boreholes in advancing faces, working seams and high-level boreholes (enclosed draining), by using a pump (2BEC42 or 2BE3-420-2BY4) linked with a 14-inch main pipe and 6-inch branch pipe. The methane content is estimated at about 15% and the volume of mixed gas is about 70m^3/min, while the volume of pure methane is about 10m^3/min with a monthly amount of 430,000m^3.

Table 9: Planned annual amount of pure methane to drain

Area	Estimated annual pure methane (10^4m^3)
11	1404
12	1602
21	1500
Total	4506

Based on weekly gas data provided by the coal mine for 2010, the actual amount of gas drainage in 2010 is estimated in Table 10:

Table 10: Gas drainage in 2010 by area (averaging in 52 weeks)

Site	Content (%)	Amount of mixture (m^3/min)	Pure amount (m^3/min)	Monthly pure amount (m^3)	Annual pure amount (m^3)	Planned monthly pure amount (m^3)
Average on high pressure pipes in Area 11	10.84	92.59	7.54	339,245	3,962,382	390,000
Average on low pressure pipes in Area 11	0.00	0.00	0.00	-	-	780,000
Total in Area 11			**7.54**	**339,245**	**3,962,382**	**1,170,000**
Average on high pressure pipes in Area 12	17.25	101.78	17.04	766,907	8,957,474	475,000
Average on low pressure pipes in Area 12	10.20	149.18	15.85	713,126	8,329,308	860,000
Total in Area 12			**32.89**	**1,480,033**	**17,286,782**	**1,335,000**
Average on high pressure pipes in Area 21	9.43	48.91	4.68	210,469	2,458,284	430,000
Average on low pressure pipes in Area 21	8.22	167.67	14.13	635,653	7,424,431	820,000
Total in Area 21			**18.80**	**846,123**	**9,882,715**	**1,250,000**
Total					**31,131,879**	**45,060,000**

Table 10 shows that the actual amount of gas drainage is 69% of the planned amount in Zhongling mine. Coal production in Zhongling mine was just a third of its designed capacity, nearly 1 million tonnes in 2010. It seems reasonable to drain less gas than planned since the coal production is low. It could be assumed from the table that the actual amount of gas drained might be much more than planned when its coal production reaches 3 million tonnes.

3.2.2.4. Concentration of gas drained

Based on monitoring data of gas drained from Zhongling mine, the following figure is made, including concentration changes in three areas in 2010. It indicates that although gas concentration in Area 12 fluctuates, in most cases it is above 10%; gas concentration is stable at about 10% in Area 21, and changes between 5-10% in Area 11.

This result is far from the designed values at least due to technical problems, for example a tunnel collapse in Area 11 seriously damaged the drainage pipelines, leading to gas spillage in pipelines and consequently low gas concentration.

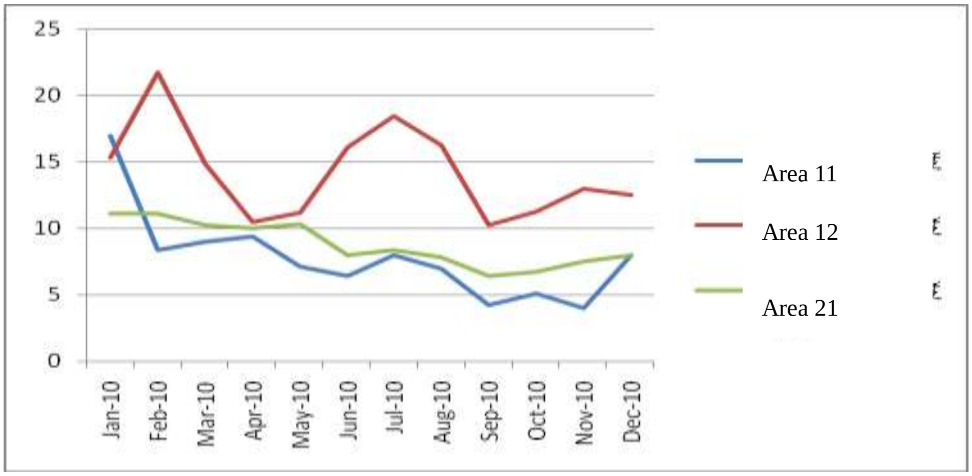

Figure 4: Comparison on methane concentrations in Area 11, 12 and 21 in 2010

The two-month gas monitoring data from October 17 to December 12 2010 in Area 11 shows that the gas concentration from the pump station is obviously lower than that from the draining points, which implies that gas concentration could be remarkably increased by careful inspection and maintenance of drainage systems.

Table 11: Gas concentration data during October 17 and December 12 2010 in Area 11

	2010-12-12	2010-12-5	2010-11-28	2010-11-21	2010-11-14	2010-11-7	2010-10-31	2010-10-24	2010-10-17
Site	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
High pressure pipes	4	4	3	4	4	4	4	3	3
113 cross entry(closed)	29	29	21	26	30	25	26	9	3
11031return air tunnel(closed)	21	21	5	25	25	29	29	25	38
11031transport roadway(closed)	11	12	4	19	18	18	19	11	14
1640 crossing-layer drainage in main	25	25	20	27	33	34	32	22	49

tunnel									
111 old cross entry before closed	2	7	5	7	11	11	11	8	12
11033 return air tunnel	9	9	20	11	7	8	9	11	10
11033 transport roadway	4	4	3	3	3	3	3	4	3

According to pure methane data at drainage sites together with monitoring data, it is imperative for the mine to periodically check the gas drainage system, especially the parts where the pure methane quantity of the drained gas is small or the concentration is low. Some draining could be ceased temporarily, where necessary, without affecting mining safety.

Table 12: Pure methane flow during October 17 and December 12 2010 in Area 11

	2010-12-12	2010-12-5	2010-11-28	2010-11-21	2010-11-14	2010-11-7	2010-10-31	2010-10-24	2010-10-17
Site	(m^3/min)	(m^3/min)	(m^3/min)	(m^3/min)	(m^3/min)	(m^3/min)	(m^3/min)	(m^3/min)	(m^3/min)
High pressure pipes	5.53	5.72	4.30	5.72	6.29	6.19	6.08	4.57	4.49
113 cross entry(closed)	2.00	2.00	1.05	1.81	2.07	1.75	1.81	0.65	0.72
11031 return air tunnel(closed)	0.30	0.30	0.04	0.30	0.30	0.35	0.35	0.17	0.36
11031 transport roadway(closed)	0.32	0.34	0.12	0.53	0.51	0.51	0.53	0.31	0.32
1640crossing-layer drainage in main tunnel	0.99	1.01	0.77	1.21	1.46	1.50	1.42	1.37	1.38

111 old cross entry before closed	0.03	0.11	0.04	0.11	0.18	0.18	0.18	0.06	0.19
11033return air tunnel	0.83	0.83	0.53	1.02	0.74	0.84	0.94	0.99	1.04
11033 transport roadway	0.89	0.89	1.75	0.66	0.67	0.67	0.67	0.93	0.63

3.3. Current situation of gas utilization

Currently, Zhongling mine has established gas power stations in three mining areas, all of which use low concentration CMM for power generation. There are four units (500 KW) installed in Area 11. However, due to drainage issues in this area, there has been inconsistent gas supply for power generation. Six units (500 KW) are installed in Area 12 and are operating. Five units (500 KW) are installed in Area 21 and are also generating power.

The average rate of CMM utilization in Zhongling mine is only 20.48%. There is great potential to utilize existing CMM, especially at Area 12 where a large amount of CMM is available for use.

4. Energy production and consumption in Guizhou

In attempt to provide a context for the use of coal mine methane, this section briefly introduces the energy production and consumption in Guizhou, with focus on Guizhou's coal, natural gas, and electricity market. For details of this section, please refer to the overall project report.

4.0.1 Energy production

Coal is the most important energy source in Guizhou. From 2005 to 2009 its proportion in energy production has been above 85% (see Figure 5 and Figure 6).

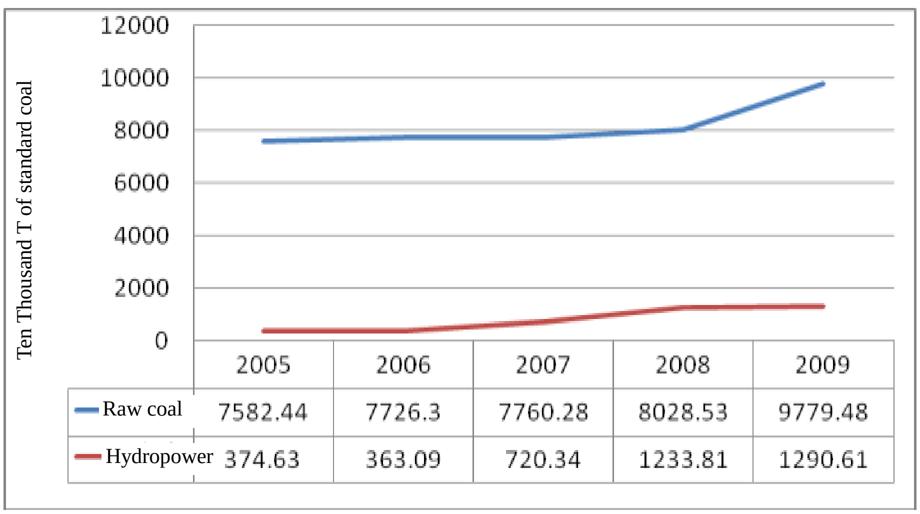

Figure 5: Energy production by fuel from 2005 to 2009

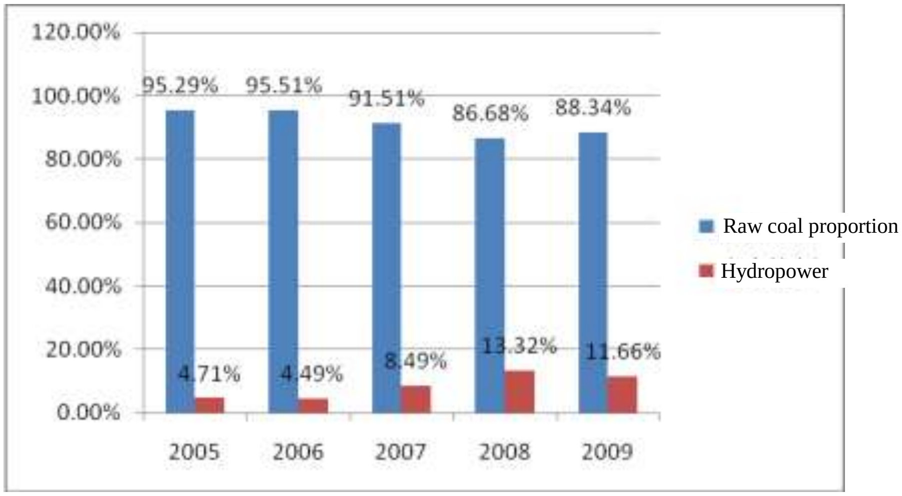

Figure 6: Energy production by fuel in percentage from 2005 to 2009

4.0.2 Energy consumption

According to "China Statistical Yearbook 2009", coal accounted for 68.7% of total energy consumption in China, and the coal-dominated energy consumption structure is unlikely to change, which is particularly true in Guizhou where coal reserves are rich. According to "Guizhou Statistical Yearbook 2010", from 2005 to 2009, coal consumption accounted for over 55% of total energy consumption in the province (see Figure 7 and 8).

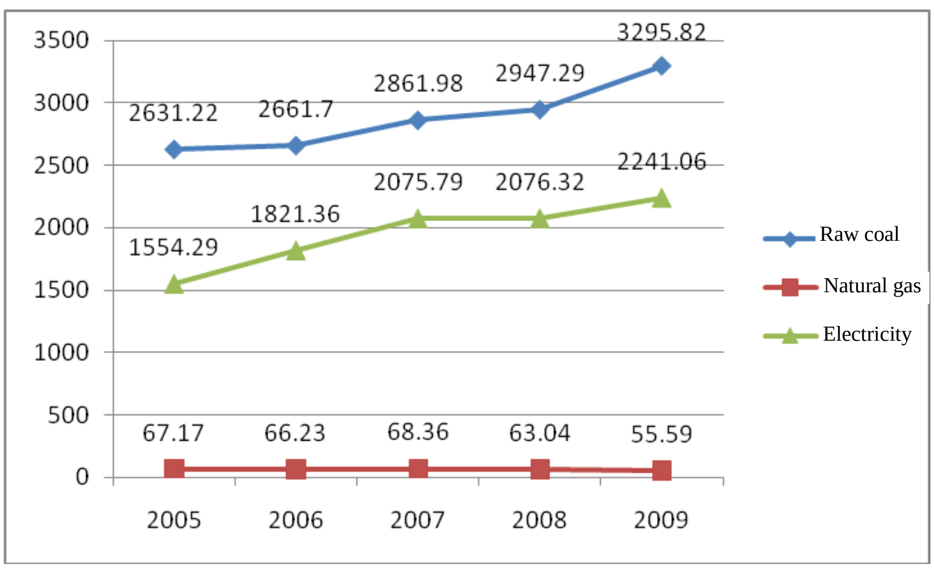

Figure 7: Energy consumption by fuel in Guizhou

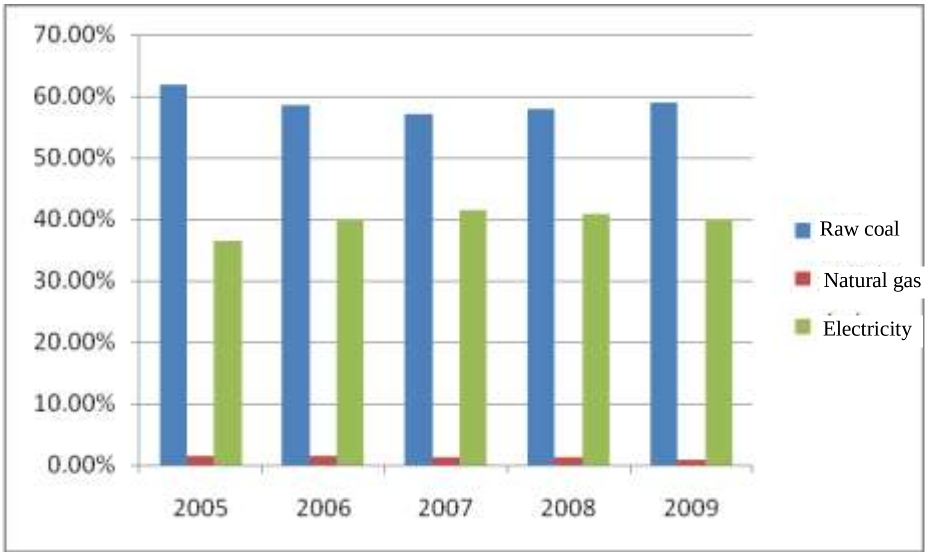

Figure 8: Energy consumption by fuel in percentage in Guizhou

Above figures show that coal is the main energy source in Guizhou. This coal-dominated energy structure will not change over a long period in the future, and the demand for coal will keep growing.

4.1. Guizhou's coal market overview

4.1.1 Coal consumption and demand forecast

According to Guizhou Statistical Yearbook, 2009, total coal consumption for the whole province in 2009 was 13.1 million tonnes, of which the largest proportion (35.5%) is taken by the power industry. The proportion of coal consumption for various industries is in Figure 9. According to development plans for the industries, the energy consumption for the industries during the "Twelfth Five-Year Program" period is estimated in Table 13.

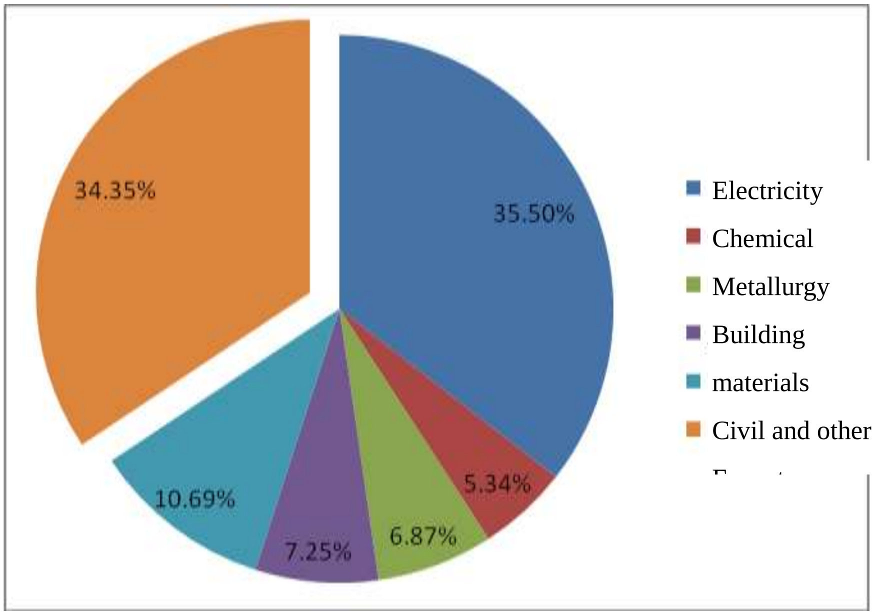

Figure 9: Energy Consumption by industries in Guizhou Province in 2009[3]

Table 13: Coal demand forecast in Guizhou in the "Twelfth Five-Year Program" (Unit: ten thousand tonnes)

Coal consumption	"Eleventh Five-Year program"	"Twelfth Five-Year Program" (Planning)					Projection
	2010	2011	2012	2013	2014	2015	2020
1. Power industry	4820	5540	6490	7140	8580	9910	12400
2. Chemical industry	1610	1650	1800	2200	2500	3230	4830
3. Metallurgical industry	1050	1160	1250	1500	1650	1900	2100
4. Building materials industry	1000	1000	1050	1050	1100	1100	1100
5. Civil and other	1500	1380	1360	1300	1200	1100	1100
Total demand for the	9980	10730	11950	13190	15030	17240	21530

[3] Export volume refers to the amount of coal that is transported to other provinces (autonomous regions and municipalities). The surrounding areas of Guizhou Province (Chongqing, Sichuan, Yunnan, Guangdong, Guangxi, Hainan, Yunnan, Hubei, Hunan, etc.) are mostly coal import areas where coal resources are poor. Transferring from Guizhou Province can save considerable transportation cost over the "Coal transportation from North to South project".

province							
6, Export volume *	3500	4000	4000	4000	4000	4000	4000
Total coal demand	**13480**	**14730**	**15950**	**17190**	**19030**	**21240**	**25530**

* The export volume includes the equivalent amount of coal used for coke products exported

The following conclusions could be made on the basis of the above analysis:

(1) The coal production driven by power generation is still an important factor for coal demand growth in the future; the advanced coal chemical industry is an important growth drive for future coal demand.

(2) The forecast of coal demand has taken into account energy savings that would be brought about by technological progress, in account with some unexpected factors; if energy saving achieves the goal, the demand would decrease.

4.1.2 Analysis on Guizhou coal supply and demand balance

The production capacities of existing mines in Guizhou and yield forecasts are shown in Table 14; the coal supply and demand balance is shown in Table 15. As can be seen from Table 14, during and at the end of the Eleventh Five-Year program, the mines with annual output less than 300,000 tonnes of coal were still the mainstream and major coal producers. Through restructuring in Twelfth Five-Year program, mines with annual output more than 300,000 tonnes will dominate this industry in 2015; capacity of mines with annual output less than 300,000 tonnes will be greatly reduced. As can be seen from Table 15, in accordance with output arrangement for existing registered mines and mines under construction till the end of 2009, the supply and demand in 2009 was basically balanced. The supply-demand balance difference will be 30.07 million tonnes at the end of the "Twelfth Five-Year Program" (2015), and 86.77 million tonnes at the end of the "Thirteen Five-Year Program" (2020). The supply and demand of coal will show a trend of further expansion in this period, and demand will see significant increase.

Table 14: Existing coal production capacity and output prediction of Guizhou province

Project	Quantity (pairs)	Production capacity (ten thousand t/a)	Production by year (million t)			
			2009	2010	2015	2020
Existing coal	1738	29347	13691	15363	18233	16853

mines							
of which	≥300 000 t / a	234	11798	3155	4493	14155	14590
	<300 000 t / a	1504	17549	10536	10870	4078	2263

Table 15: Existing coal supply and demand balance and forecast of Guizhou Province

Items		2009	2010	2015	2020
Coal demands (ten thousand tonnes)		13100	13480	21240	25530
Supply of coal (ten thousand tonnes)	Existing coal mines	13691	14875	9405	7395
	Mines under construction (as of 2009)		488	8828	9458
	Total	13691	15363	18233	16853
Supply-demand balance difference (ten thousand tonnes)		+591	+1883	-3007	-8677

4.1.3 Coal market around Zhongling mine

Zhongling mine mainly supplies coal to Nayong No.1 Power Plant in Nayong County. Built in 2004, the power plant is 8.5 km from Zhongling mine with installed capacity of 1.2 million kilowatts (4 x 300MW) and annual anthracite consumption of 3 million tonnes. Following No.1 power plant, Nayong No.2 Power Plant was completed in 2006. It is only 9 km way from No.1 power plant and has same installed capacity (4 x 300MW) and annual coal consumption. Zhongling mine is the matching coal mine for the so-called "large coal production guarantees large power plants" under the project of "West to East Electricity Transmission". Currently coal is transported by truck to the plants. The Nayong Power Plant is now constructing a coal belt transport system, which is planned to be completed by the end of 2011 and be able to transport coal directly from Zhongling mine to Nayong No.1 Power Plant.

In terms of demands from local power plants, there is no problem for Zhongling mine to sell its coal. The only factor is the price. Currently, the price of coal sold from Zhongling mine to Nayong power plant is stable at about 300 Yuan per tonne. The price is very low for the mine. But it is difficult for the mine to get a satisfactory price since coal pricing for power generation usually subjects to local government's regulation. If coal from Zhongling mine is to be sold outside Nayong County, the local government is to add 100-200 Yuan for each tonne of coal. In this way, Zhongling mine has almost no choice to sell the coal to the nearby power plants. As a result, Zhongling mine would continue to produce and supply coal to the power plants as long as they continue to generate electricity.

4.2 Guizhou gas market

4.2.1 Gas consumption

As of 2009, gas supplies in cities of Guizhou were: coke oven gas 300 million m^3 / year, natural gas (excluding for Chitianhua's fertilizer production) 50 million m^3 / year, liquefied petroleum gas 82,000 tonnes / year. The number of gas users in the province was 3.58 million (Guizhou Province's total population is about 40 million), in which liquefied petroleum gas users accounted for 47.49%, artificial coal gas users accounted for 49.38%, natural gas users accounted for 3.13%. The detailed data are shown in Table 16.

Table 16: Gas user by population in Guizhou in 2009

No.	Source	City	Population (million)	Proportion
1	Artificial coal gas		176.78	49.38%
1.1	Coke oven gas	Guiyang	149.8	
		Qingzhen	10.5	
		Liupanshui	16.2	
2	Natural gas		11.17	3.13%
2.1	Natural gas	Guiyang	1.1	
		Zunyi	2.1	
		Zunyi county	0.13	
		Anshun	0.06	
		Duyun	0.06	
		Renhuai	0.1	
		Xingyi	0.07	
		Bijie	0.28	
		Kaili	0.3	
		Chishui	2.07	
2.2	CMM	Liuzhi	4.9	
3	LPG		169.97	47.49%
3.1	Bottled LPG	Whole Province	16.776	
3.2	Pipeline LPG	Tongren	0.14	
		Huishui	0.11	
		Qianxi	0.42	
		Weng'an	0.21	
		Zunyi	1.05	
		Meitan	0.28	
Total			357.97	100%

4.2.2 Gas demand forecast

The key demands are described as follows:

1. Urban household use: It is used mainly for residential cooking and water heating, as a preferred and continuously stable gas source. Natural gas has the advantages like low price, high heat value, safety and environmental-friendly performance, and is the preferred fuel for civil gas. During the "twelfth five-year program", the quota of residential gas consumption is set as 2090MJ / person·year.
2. **2.** Commercial and public buildings: This includes the needs for production and operations or living in public facilities (such as hotels, schools, etc.) in urban and rural residential areas, as well as in governmental agencies, and research institutions.
3. **3.** Industrial users: This includes gas switched from coal, used in industrial heating and production boiler and power plant boiler, heat supply in manufacturing process (such as tobacco drying, ceramics, etc.), and as a chemical material (such as using methane as a raw material to produce chemical products).
4. Vehicle fuel: In the "Twelfth five-year program", Guizhou Gas Group put the focus on planning for deployment of gas vehicle users (Guiyang and Zunyi, and other seven prefectures or cities) on the basis of city's size of development.

Table 17: Gas demand forecast for Guizhou in the "Twelfth five-year plan"

<table>
<tr><td></td><td colspan="10">Gas Consumption by gas users across the province (100 million cubic meters/ Year)</td></tr>
<tr><td></td><td colspan="2">Residents</td><td colspan="2">Public buildings</td><td colspan="2">Industry</td><td colspan="2">Vehicle</td><td colspan="2">Total</td></tr>
<tr><td>Region</td><td>2011</td><td>2015</td><td>2011</td><td>2015</td><td>2011</td><td>2015</td><td>2011</td><td>2015</td><td>2011</td><td>2015</td></tr>
<tr><td>Guiyang</td><td>0.85</td><td>1.31</td><td>0.68</td><td>1.96</td><td>2.95</td><td>13.04</td><td>0.58</td><td>0.77</td><td rowspan="4">12.8</td><td rowspan="4">65.38</td></tr>
<tr><td>Bijie</td><td>0.47</td><td>0.74</td><td>0.38</td><td>0.6</td><td>0</td><td>2.94</td><td>0.01</td><td>0.01</td></tr>
<tr><td>Other regions</td><td>3.03</td><td>4.93</td><td>2.42</td><td>5.24</td><td>0</td><td>32.19</td><td>1.43</td><td>1.65</td></tr>
<tr><td>Total</td><td>4.35</td><td>6.98</td><td>3.48</td><td>7.8</td><td>2.95</td><td>48.17</td><td>2.02</td><td>2.43</td></tr>
<tr><td colspan="11">Note: In this table, Bijie is listed separately because they are the nearest gas supply target for Zhongling mine.</td></tr>
</table>

Table 17 shows that in the period, gas demand for industrial and commercial sectors will be increased rapidly. See the chart below for details.

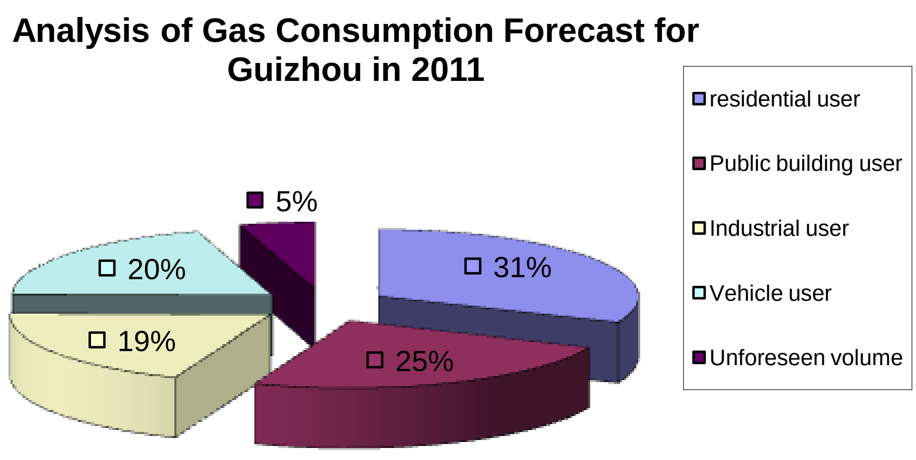

Figure 10: Analysis of Gas consumption for Guizhou in 2011

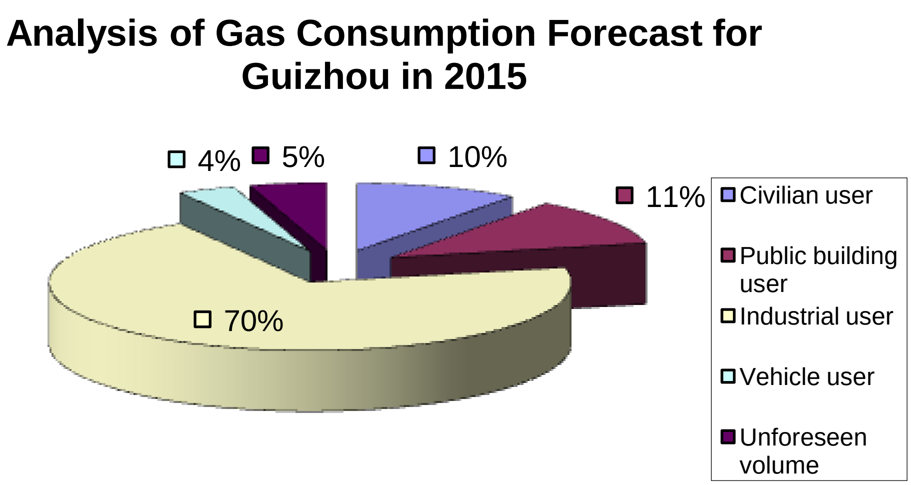

Figure 11: Analysis of gas consumption projection for Guizhou in 2015

The growth in vehicle gas consumption is very slow from 2011 to 2015. The reason might be the lack of natural gas resources in Guizhou, so in the plan, the designed amount was based on the capacity of natural gas companies. Because vehicle gas is not an important supply target, with limited gas supply, priority will be given to other key areas, such as residents, industrial and so on. However, this does not mean there is no market for vehicle gas but a truth that limited resources restrict the market.

Vehicle gas consumption forecast for Guizhou is in Table 18.

Table 18: Gas consumption forecast for Guizhou's vehicle gas user

City	Type	The number of vehicles (cars)			Gas Consumption per vehicle (cubic meters/Days)	Gas Consumption (100 million cubic meters/Years)	
		2007	2011	2015		2011	2015
Guiyang	Bus	2273	2903	3484	55	0.58	0.70
	Taxi	3069	4351	5221	30	0.48	0.57
Zunyi	Bus	408	490	588	55	0.10	0.12
	Taxi	1040	1248	1498	30	0.14	0.16
Anshun	Bus	255	306	367	55	0.06	0.07
	Taxi	479	575	690	30	0.06	0.08
Duyun	Bus	300	360	432	55	0.07	0.09
	Taxi	268	322	386	30	0.04	0.04
Liupanshui	Bus	151	181	217	55	0.04	0.04
	Taxi	912	1094	1313	30	0.12	0.14
Kaili	Bus	205	246	295	55	0.05	0.06
	Taxi	489	587	704	30	0.06	0.08
Xingyi	Bus	110	132	158	55	0.03	0.03
	Taxi	510	612	734	30	0.07	0.08
Bijie	Bus	50	60	72	55	0.01	0.01
	Taxi	321	385	462	30	0.04	0.05
Tongren	Bus	87	104	125	55	0.02	0.03
	Taxi	430	516	619	30	0.06	0.07
Total		11357	14472	17366		2.02	2.43

4.2.3 Gas supply

According to Guizhou Gas Group's plan, natural gas will become an important source of gas supply, mainly coming from the "China-Myanmar Oil and Gas Long-distance Transportation Pipeline" (expected to supply gas to Guizhou in 2013) and "Zhongwei - Guiyang gas transportation pipeline" (expected to supply gas to Guizhou in 2012). It is expected that in 2015, natural gas supply from the Long-distance pipelines will reach 1.75 billion m^3. In addition, Guizhou Gas Company, Petro China, and other enterprises in Guizhou will supply liquefied natural gas of about 376 million m^3 per year, and compressed natural gas of about 11 million m^3 per year. Other gas sources include artificial coal gas, and liquefied petroleum gas.

It is expected that in 2015, the total gas supply will be only 2.137 billion cubic meters, while the province's gas demand is expected to be 6.538 billion cubic meters. There is a huge gap. If coal mine methane is purified to make CNG / LNG, it could be an important supplement to gas supply of natural gas in certain areas. If the price is competitive, Guizhou itself will become a huge market.

4.3 Electricity market

4.3.1Current situation of electricity market in Guizhou

By the end of 2010, total installed capacity of the in-pool power generators in Guizhou Power Grid is 27.316 million kilowatts, of which the capacity of hydropower is 10.176 million kilowatts, accounting for 37% of the total; the capacity of coal-fired power is 171.4 million kilowatts, accounting for 63%. Please refer to Table 19 for details.

Table 19: Installed capacity by plant in Guizhou power Grid
(Unit: ten thousand kilowatts)

Coal-fired Power Plant	Installed Capacity	Hydro Power Plant	Installed Capacity
Anshun Power Plant	120	Dashuihua power Plant	20
Bijie Power Plant	30	Dongfeng Power Plant	69.5
Dafang Power Plant	120	Dongjing Power Plant	88
Dalong Power plant	60	Geliqiao Power Station	15
Fa'er Power Plant	240	Goupitan power plant	300
Guiyang Power Plant	40	Guangzhao power station	104
Jinsha Plant	50	Hongfeng Power Plant	26.7
Nayong Second Power Plant	120	Hongjiadu Power Plant	60
Nayong First Power Plant	120	Puding Power	8.4

		Station	
Pannan Power Plant	240	Silin Power Station	105
Panxian Power Plant	60	Suofengying Power Plant	60
Qianbei Power Plant	120	Wujiang Power Plant	125
Qianxi Power Plant	120	Yinzidu Power Plant	36
Qingzhen Power Plant	40	**Subtotal**	**1017.6**
Xishui Power Plant	54		
Yaxi Power Plant	120		
Yemazhai Power Plant	60		
Subtotal	**1714**		
Total	**2731.6**		

(Source: "Guizhou Yearbook 2010")

Electricity outputs of Guizhou in recent years see Figure 12:

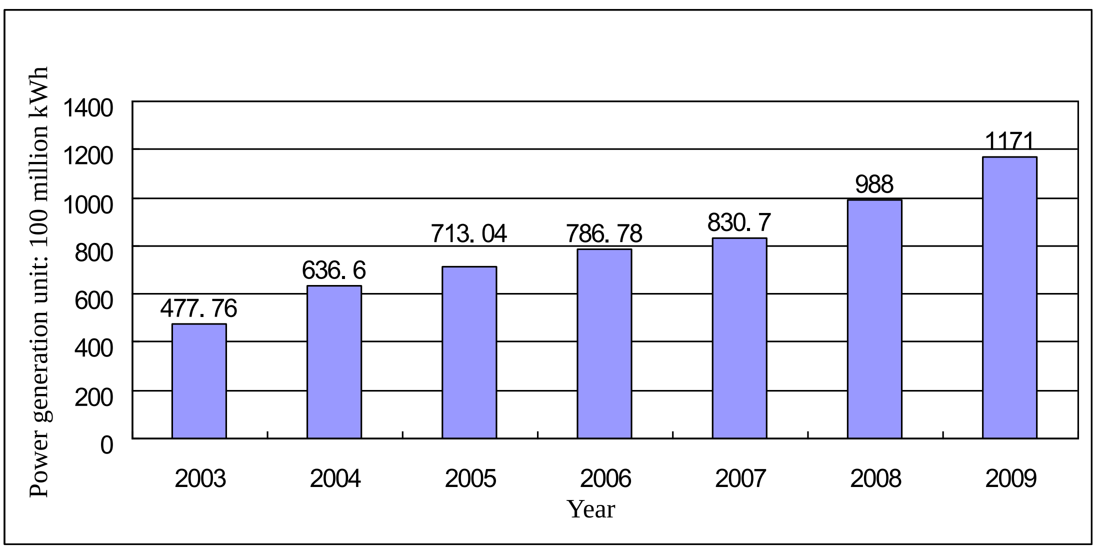

Figure 12: Electricity outputs of Guizhou in recent years

As one of the key provinces in "West to East Electricity Transmission" project, Guizhou's electricity exports in recent years are shown in Figure 13.

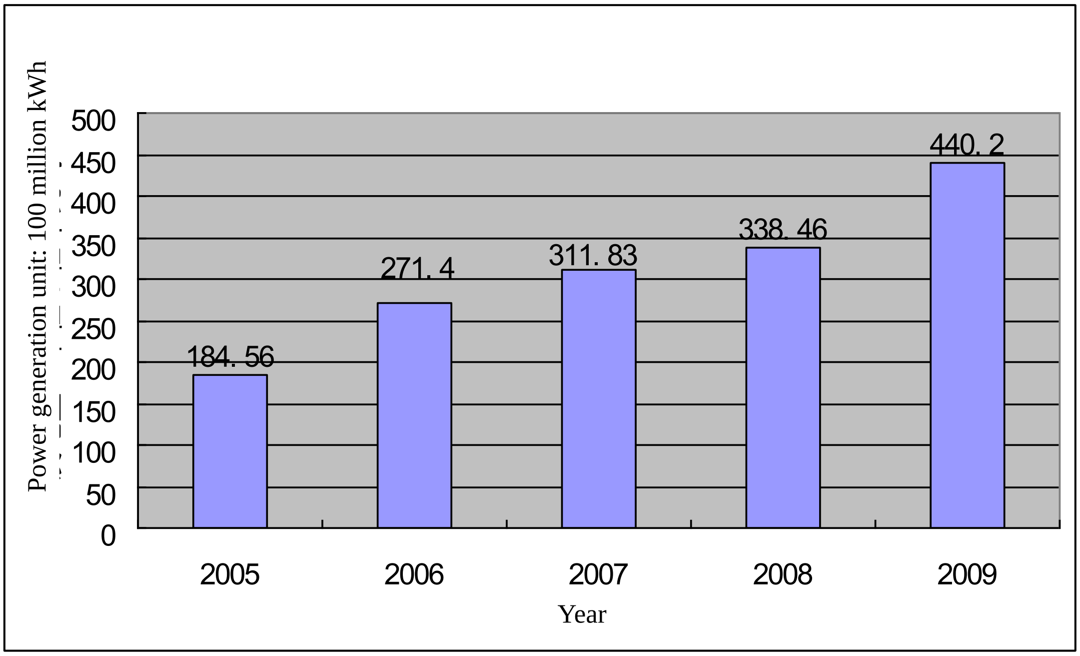

Figure 13: Guizhou's electricity exports for "West to East Electricity Transmission" project

4.3.2 Forecast for Guizhou's Electricity Market

In recent years, with steadily rapid growth of Guizhou's economy, the electricity demand has continued to boom; it is urgent to develop new or extension of energy comprehensive utilization and power generation projects, in order to ease the region's stress on power supply. In addition to continuous growth of provincial economy, urbanization, improved living standards of urban and rural residents and upgrade of residential consumption structure are the driving force of increasing electricity demand. Although technological advancement, environmental protection and energy saving will partly inhibit demand for thermal power, the increasing contribution of energy, raw materials, and heavy industry in the economy would likely make a rising trend of province's electricity demand. It is also expected that in the "Twelfth five-year program" period, electricity demand from other provinces within the China Southern Power Grid will also boost electricity demand for Guizhou (See the Figure 14).

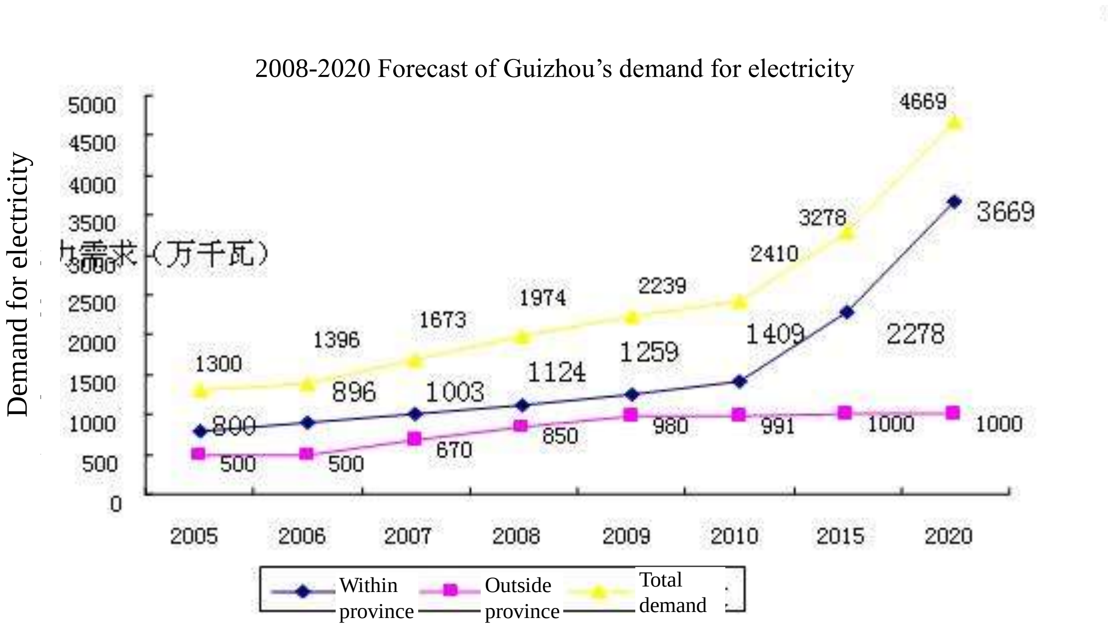

Figure 14: Forecast of Guizhou's demand for electricity

4.3.3 Guizhou electricity dispatching and pricing

Guizhou Province is covered by China Southern Power Grid. China Southern Power Grid Co. Ltd. was established and began operation on December 29, 2002, and has gradually developed into one of five state regional power grids. The grid covers five provinces (regions) including Guangdong, Guangxi, Yunnan, Guizhou and Hainan, and is responsible for investment, construction and management of power grids in south region, as well as for conducting related power transmission and distribution.

Under the country's current electricity tariff system (including sales price and feed-in tariff for power plants), in principle, the price is set by province on provincial power grid, which is approved and published by the Development and Reform Commission, and will be strictly followed and implemented by power grid companies, power plants, and the users. Currently, Guizhou's thermal power grid tariff is around 0.3131 Yuan / kWh, and hydropower grid tariff is 0.2374-0.277 Yuan / kWh. The grid's electricity sales prices differ from different users. For industrial users like coal mines, the average price is about 0.53-0.7 Yuan / kWh, and price changes with actual consumption; the greater consumption of electricity is, the cheaper the price is.

4.3.4 Market potential for CMM power plant

As shown above, power plants in Guizhou that are connected to the grid for dispatching are all large-scale thermal power or hydropower plants. Because of the limited amount of CMM in Guizhou, the potential for large-scale CMM power generation onto the grid is very small. Therefore, to ensure availability and stability of power supply, the power grid company certainly prefers to purchase electricity from large thermal power or hydropower plants. However, in order to promote the use of CMM, the Chinese government developed preferential policies to encourage CMM power generation and grid connection: In principle, electricity from CMM power plants should firstly be supplied to captive consumption of mining; for any surplus that need to feed into the grid, the power grid companies should not only give priority to sales to the grid, but also provide convenience for grid access, and be responsible for grid connection to common joints. The grid tariff of electricity from CMM power plant would be referred to price of grid connection for biomass power generation projects with a subsidy of 0.25 Yuan per kWh based on the benchmark price for desulfurization units in 2005.

If it is implemented in accordance with China's policies that encourage gas power generation, the economic benefit of a gas power plant would be substantially enough to motivate coal mines to generate electricity by using CMM. But regrettably, only one gas power plant in Guizhou (Hongguo coal mine gas power plant in Panxian County) is so far known to obtain approval of electricity grid price from the Guizhou Pricing Bureau, at the price of 0.517 Yuan / kWh. The remaining gas power plants were originally designed only for captive electricity consumption of coal mines, without considering selling electricity to the grid. This has resulted in a large amount of surplus CMM not to be fully utilized. The main reasons are described as follows:

- The National Development and Reform Commission (NDRC) stated that the price difference, 0.25 Yuan/kWh over the benchmark grid price for local coal-fired power generation unit with desulfurization facility, can be covered by raising the provincial power grid’s sale price where CMM power plant locates. However, Guizhou has not yet formulated any measures with price subsidies while surcharge of renewable energy on sale price has been paid to the state. Currently the inverted difference between CMM power generation price and sale price is paid by the grid company. This obviously is not a sustainable option and will negatively affect the willingness of the power grid company to feed in CMM power.

- Power grid connection for CMM power generation needs to be approved by the Development and Reform Commission, the Power Regulatory Office, the Planning Bureau, Price Bureau, Environmental Protection Bureau, Land and Resources Bureau, Power Supply Bureau and other authorities. This complicated approving process creates a psychological barrier for coal mine owners.

- At present, there are no comprehensive CMM utilization plans for the whole province and individual coal mines. The existing CMM power plants are all built by coal mines themselves without integrated involvement of local authorities. Especially for local small coal mines, despite some having desire to invest, most of them failed to undertake CMM power generation and grid connection due to less understanding of CMM power generation and their own CMM conditions.

- Some CMM power plants failed to go through normal approval procedures and did not comply with national procedures for infrastructure construction, including feasibility study, government approval, application of power grid connection, signing agreement to connect power grid, design and review for power grid access, eligible construction, inspection and acceptance. This made it difficult for the power grid to coordinate with actual production and operation of the plants, thus resulting in delay or even failure of grid connection of CMM power generation.

- Subject to limited total available gas volume and means of drainage, as well as unstable methane concentration, power generators of some power plants do not work stably with frequent start and stop. This poor operational reliability imposes potential hazard to coal production safety and stable grid operation, which makes it difficult for power grid to conduct normal operation and dispatch.

Interviews with management of Zhongling mine revealed that its CMM power generation units are operated by Qunlian Industries Company (which was arranged by its parent company, Shuicheng Mining (Group) Co., Ltd.), while its CMM is used for power generation free of charge and the generated electricity is sold to Zhongling mine. Under this context, Qunlian Company is also constrained to sell surplus electricity to the grid and is not motivated to utilize surplus CMM by adding more generators. In order to make full use of CMM in Zhongling for power generation, grid connection would be essential.

5. Technical options for gas utilization

The main component of CMM is methane, which has the heat value equivalent to that of natural gas[4], and can be mixed with natural gas for transportation and use. Moreover, it will not generate any exhaust gas besides CO2 after burning, and is a clean and cheap fuel for industrial, chemical, power generation and resident living. The potential of using CMM is determined by its heat value which is related to content of methane (CH_4). It can be said that the method of CMM utilization depends largely on the concentration of methane.

5.0.1 Selection of utilization methods

For assessment of CMM utilization methods, not only the chemical and physical characteristics like concentration and stability of methane in CMM drained should be considered, but also the impact of socio-economic environment on the method of utilization, for which there is no general standard. It should be based on an analysis of gas sources, considering the exploitation condition of local resources, market conditions and laws and regulations, to choose the most appropriate ways of utilization.

Internationally, there are different points of view in the industry concerning the economy and safety of CMM utilization, due to different gas source endowments and operational environments in different countries. For example, according to the UNECE / Methane to Markets Partnership's "Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines"[5](hereinafter referred to as "Guidance"), coal mine methane utilization projects have been divided into categories of medium / high concentration (30% -100%) and low concentrations (<30%); it is believed that the low concentration gas can only be destroyed or purified to high concentration gas before use because of its risk of explosion in the course of transmission.

In China, more than 60% of CMM drained is of low concentration with methane content lower than 25%. In response to this national situation, China has developed low concentration gas power generation technology that is adopted by a increasing number of coal mining enterprises, with proven economic, safety performance in practice; the Chinese government has issued safety standards for low-concentration gas utilization, which practically accepted the utilization method.

The Guidance publication studied 240 gas utilization projects around the world which

[4] Specifically, the heat value of 1 standard cubic meter CMM gas is equivalent to 1.13kg of gasoline, 1.21kg of standard coal, 9.5 kWh electricity, 1 liter of diesel, close to 0.8kg of liquefied petroleum gas, 1.1 to 1.2 liters of gasoline.

[5] http://www.unece.org/fileadmin/DAM/energy/se/pdfs/cmm/pub/BestPractGuide_MethDrain_es31.pdf

are either in operation, or under construction or plan, and summarized the potential uses of CMM with methane concentration of 30%-100%. The use purposes include: 1) as fuel for steel-making furnaces, kilns and boilers; 2) as fuel for internal-combustion engine or steam turbine power generation; 3) injected into natural gas pipeline for gas distribution; 4) as a raw material for fertilizer production; 5) converted into LNG or CNG for use as motor fuel. Most applications in these projects are related to power generation, natural gas pipelines and boilers. In addition, the Guidance also analyzes how carbon credits or other environmental goods can stimulate the uses of gas.

The Guidance compares potential use patterns of medium to high concentration gas, and describes the ways for purification and destruction (not use) of low concentration gas (including ventilation air methane).

Table 20: Comparing methods of using coal mine gas

Use	Application	Advantage	Weakness
Power Generation	Gas power generation units, for captive consumption or feed to the grid	• Proven technology • Waste heat recovery, supply heat for the mine area, and miners' bathhouse, and provide thermal energy for heating and cooling	• Easily influenced by mining activities and encounter problems in output fluctuations; not conducive to grid connection; • Routine maintenance requires increased attention of mines • Huge investment in initial phase of the project
High concentration pipeline gas	Purification and production of high concentrations gas	1) Equivalent of natural gas 2) Profitable in areas of high pricing 3) Good choice for places with good pipeline infrastructure	• High standard for pipe cleaning, high cost of purification • Only applicable for high-quality pre-draining or processed coal mine gas • Require reasonable access to the pipeline
Medium concentration civil gas or industrial gas	Methane with concentration of greater than 30% can be used for	• Low fuel cost • Regional benefits • Less demanding on purification	• High cost of delivery systems and maintenance • Concentration and

Use	Application	Advantage	Weakness
	household fuel, district heating and industrial boilers, etc.		supply fluctuations • Project operators need high investment to deal with peak demand
Chemical raw materials	High concentration gas can be used in manufacturing of carbon black, formaldehyde, synthetic fuels and DME	• Utilization of excessive high concentration gas	• High processing cost • Excluded from clean development mechanism when producing carbon emissions
Coal mine self consumption	Miner dorms heating, gas, boilers and pulverized coal drying	• Alternative of coal • Clean, with low energy costs	• More economical using in mining area than transporting to outside
Vehicle fuel	Pre-drained high concentration gas and coal bed methane can be purified to produce CNG and LNG	• Methane will go into the market • High fuel prices for vehicle	• High cost of processing, storage, handling and transportation • High standard of purification
Torch combustion	Methane is destroyed, no application	• Clean and efficient emission reduction • No energy consumption	• Concentration of methane must be above 25% • The initial investment will not bring about economic return
Oxidation of ventilation air methane	Methane is destroyed, no application	• Waste heat recovery	• High investment costs

Note: If a project can achieve the required standards, then it will qualify for carbon credits, new energy credits, or eligibility for fixed-price credit.

5.0.2 Technology options for gas utilization and emission reduction: exploration and practice in China

In the late 1980s and early 1990s, China began to carry out a more systematic exploration program on coal mine methane utilization. The country used energy-saving investment funds to construct 56 coal mine methane utilization projects, supplying the drained gas for domestic use, manufacturing carbon black and formaldehyde as well as other chemical raw materials. In recent years, low concentration gas for power generation has received growing attention. But in general, the ways to utilize gas in our country is relatively limited; the current utilization rate is less than 30%, and there is great potential for further use.

It should be noted that the low concentrations of gas might be caused by natural characteristics of coal bed methane, wrong drainage method, or improper installation standards for drainage system. The latter will not only lead to low draining rate, but will also mix too much air, dilute methane concentrations. The biggest challenge in utilization of low concentration gas is how to eliminate the explosion risk in transportation and use of gas with concentrations close to the explosion limit of methane.

It is originally stipulated in section 148 of China's "Coal Mine Safety Regulations"[6] that gas can only be used when its concentration is above 30%. But according to "Decision to modify terms in Coal Mine Safety Regulations"[7], State Administration of Production Safety Supervision and Management's No. 29 Decree, which was passed on December 14, 2009 and came into force on March 1, 2010, the same stipulation was reinterpreted to: "When the concentration of drained gas is less than 30%, it should not be put to direct combustion; when used for internal combustion engine power generation or for other purposes, the use and transportation of gas must comply with provisions of relevant standard, and must develop related technologies and measures." This is to confirm that once appropriate technical measures are developed in accordance with relevant standards and requirements, low concentration gas can still be used.

Here is a brief introduction of different ways of utilization in China that have been used or are under development, with consideration of their applicability to high and low concentration gas. Methods of low concentration gas destruction are not in the scope of our discussion. This is because according to recommendations of the current "CBM (coal mine methane) emission provisional standard"[8], only high concentration gas (>30%) can be disposed by burning. The utilization technology of ventilation air methane has matured, but because the destruction of ventilation air methane doesn't create direct economic benefits, it relies entirely on carbon credits. With the expiration of the "Kyoto Protocol" in 2012, the market outlook for carbon credits is still unclear, and the coal mines or investors are fairly cautious about ventilation air methane destruction projects. The current situation is that the vast majority of China's coal mines will discharge ventilation air methane directly; as a result, this study will exclude the destruction of ventilation air methane.

[6] http://www.chinasafety.gov.cn/files/2004-12/09/F_42cd456f6a924f7f8d36815edaa3e531.pdf
[7] http://www.chinacoal-safety.gov.cn/Contents/Channel_5351/2010/0126/83596/content_83596.htm
[8] See http://www.ep.net.cn/ut/bz/2008/gb21522.pdf

The foregoing section has analyzed operation and market conditions for two gas utilization methods, including power generation gas manufacturing. We will focus on process and technology configurations of the two methods.

5.0.2.1 Coal mine methane power generation

Currently, the mainstream technology for gas power generation is to use internal combustion engines for power generation. In China, it can be divided into two types according to the gas concentration being used: low concentration gas power generation (using gas concentrations of less than 30%, usually about 10%) and high concentrations gas power generation (using gas concentration of 30% or more). The former application will use domestic-made generator units; the latter application use mainly imported units.

Low-concentration gas utilization technology has long been controversial; and the focus of discussion is about its safety issues. In 2010, the State Administration of Production Safety Supervision and Management issued safety technology conditions for non-metallic gas transmission pipe for coal mines, technological conditions for automatically explosion arrestment device for gas pipeline transmission, safety system design specifications for low concentration coal mine methane pipeline, specification of safe transmission equipment for mixture of coal mine low concentration gas and water mist, etc. and other 10 industry safety standards for low-concentration gas transportation and utilization, and came into force since July 1, 2010. This represents that the Chinese government has recognized the technology of low concentration gas utilization.

In Guizhou, the state-owned medium- and large-scale coal mines and some township coal mines are mostly using low concentration gas power generation technology and equipment, and the efficiency of gas power generation is generally low. For example, the efficiency for domestic generators is generally equivalent to 2.5 kWh per cubic meter of pure methane. If high concentration gas is used for power generation, they usually use imported generators with high efficiency that can reach 4 kWh. But the equipment is expensive, and the requirement for source of gas is higher.

According to relevant national regulations, the coal mines can carry out low concentration gas generation as long as the following conditions are met: first, the installation of a gas drainage system according to a requirement of the national coal mine Safety administrations, and the gas drainage systems must be running; secondly, the pure methane drainage volume of gas drainage system must be 1 million m^3 / year or so, with gas concentration of between 6-25%. The construction of gas power plants can achieve virtuous cycle of development by "promoting draining through utilization" and “promoting mining through draining" in coal mines. Its power generation principle is simple, and the investment amount in domestic equipment is relatively low, and is currently the major gas use pattern in China[9].

Gas power generation is the main pattern of gas utilization in Guizhou Province, and the following process route is commonly used:

Coal seam or gob →Φ60 drainage pipe at multiple points→ Regulation tube for mix of different concentrations → Φ400 main pipe →Air pump for draining and supply →

→Power plant →Generator →Voltage up conversion → Regional transmission lines → Voltage down conversion →Coal mine production and living facilities

Figure 15: Typical process route adopted by Guizhou's low concentrations gas power plants

5.0.2.2 Gas purification, compression, and liquefaction

A. CNG or LNG

The mass utilization of methane as an alternative fuel is faced with two major bottlenecks: first, the distribution of CMM gas wells feature characteristics of "remote, scattered, and small"[9] and gaseous methane has huge volume which makes it costly to install long-distance, large-scale gas pipeline network (such as " West to East Electricity Transmission" project). At the same time, the mass of a given volume of gaseous methane is very small; the released energy is insufficient to support industrial production in need of large energy consumption. Building chemical plants or large gas power plants in the vicinity of CMM fields will not only involve large investment, but also need long-term and stable supply from large gas source; small power plants are very difficult to connect to the grid, so all these utilization methods are not possible to realize long-distance transmission of energy.

For areas where a gas pipeline is not accessible, non-pipeline transportation methods can be used just like those methods with conventional natural gas. One way is through liquefied natural gas (LNG), which is obtained when CMM is frozen to -162 °C under normal pressure to become liquid. Then the liquefied gas is transported in low

[9] Specifically, "distant" refers to the gas sources that are far away from large industrial area, and big city neighborhoods; "scattered" refers to gas wells distributed over large area and lack of concentration, so the gas sources can't form significant scale; "small" means that the single well production is not big enough, the reserves is limited, and the mining period is short.

temperature container by rail or road to LNG satellite stations in all cities and towns. Another way is to purify and compress the CMM to prepare compressed natural gas (CNG), which will be filled into high-pressure cylinder, and be trucked to CNG filling stations in various cities and towns at room temperature.

The production and distribution processes of CNG and LNG are similar. Although the CMM converting processes, existing forms of the product, filling and storage, and gas supply systems vary between CNG and LNG, they need to reduce pressure through regulating the valve to provide gas for terminal use (see below).

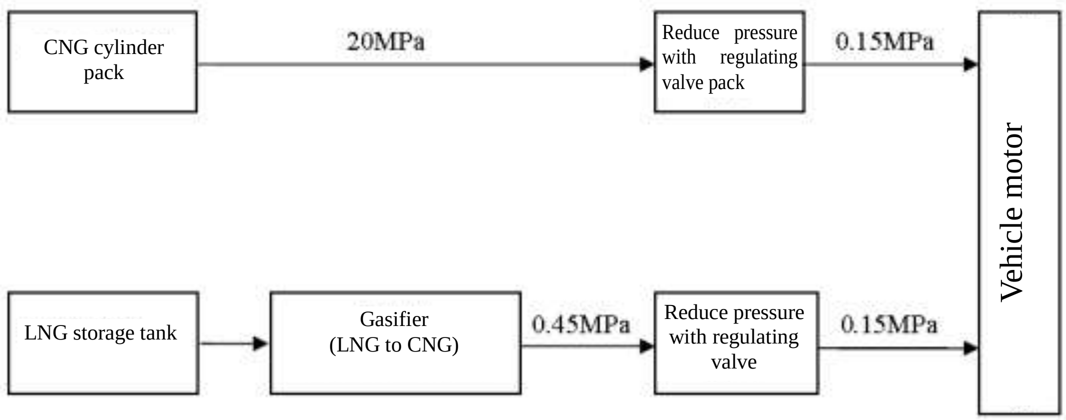

Figure 16: CNG/CNG, LNG/LNG vehicle fuel supply system diagram

Generally, adopting the above two gas supply approaches require to meet the following basic conditions: first, the drained gas should have high concentration of methane and sufficient gas volume; second, there should be relatively convenient transport facilities to ensure tanker transport; third, the gas supply region should build gas tanks to meet peak demand, and ease the shortage of gas in case of draining disruption; fourth, the gas supply terminals should have established LNG gasification stations or CNG regulation stations, to meet terminal needs for LNG "Gasification"[10] or CNG "Pressure reduction".

There are two forms of CNG filling stations, standard stations and primary-secondary station. Standard stations are built at the end of a city's medium- or high-pressure pipeline network where it is easy to operate; CNG secondary-stations are built within the range of tens kilometers away from the primary station, in this way, gas supply is guaranteed and it allows for flexible distribution of stations. LNG stations take a similar form with CNG / CNG primary-secondary stations, with filling stations generally stay away from "primary station", the liquefaction plant. Currently, LNG gas sources can only

[10] For "Gasification", there are two methods. One method is to use high-pressure cryogenic pumps to drain cryogenic liquefied gas directly into high pressure liquefied gas, and then process through high pressure gasifier; the second method is to gasify through gasifier, then compress gasified methane into CPCM through a gas compressor.

deliver through tankers from LNG liquefaction plants several thousand kilometers away to vehicle filling stations with poor gas supply security; locally produced LCMP can be used for backup gas source.

The production and process of CNG from CMM are similar. Although its production cost is lower than that of LNG, the filling process is more complex, and there are more required production equipments with bigger floor area, so the LNG filling stations will incur higher investment of construction. According to relevant statistics, the investment for building 6 CMM spherical tanks with 1Mpa of pressure and l000 m^3 of volume, is 80 times higher than building a comparable LNG tank with 0.5Mpa of pressure and 100 m^3 of volume. Meanwhile, CNG needs to be stored under high pressure (20Mpa - 25Mpa), and it safety performance is lower than that of LNG. The advantage of CNG is that it can be stored at room temperature, and the storage devices generally do not need treatment for thermal insulation.

Coal mine methane LNG needs to be stored in a liquid state under ultra-low temperature (minus 165 ºC), which is better than CNG’s gaseous storage. Although its storage is vacuum insulated, for long-term storage, there would still be evaporation and leak, with shelf life not as long as that of CNG. On the other hand, LNG storage pressure is far lower than what is required for CNG, and therefore its safety performance is better. In addition, LNG has higher energy density per unit volume than CNG, which makes long-distance transportation more economical.

Sporadic economic and technical comparison indicates[11] that when supply of gas is smaller, transportation distance is shorter, we can use CNG for gas supply; when there is a reliable source of gas supply, with larger gas supply, and longer gas distance, because of the lower cost of LNG gasification and transportation, it has an obvious comparative advantage.

Table 21: Production and gas supply process comparison between LNG and CNC

<table>
<tr><td>LNG production process</td><td colspan="2">Feed gas →filtering and metering → compression→ purification →liquefying and separation → Storage and transportation → LNG product</td></tr>
<tr><td rowspan="2">LNG supply process</td><td rowspan="2">CMM liquefaction plant →tankers → urban gasification Station →</td><td>→Urban gas pipe network →end users</td></tr>
<tr><td>→LNG vehicle</td></tr>
</table>

[11] As China Gas Equipment Net, "CNG and LNG gas source of economic analysis”, 2010-12-14, http://www.ccgas.net/conn/x1.asp?id=191&cnmai=1; Lu Miao, "The development of small towns LNG and CNG supply analysis ", 2009-9-11, http://news.gasshow.com/News/SimpleNews.aspx?newsid=220060.

CNG production process	Feed gas →metering and regulation → purification → compression → dewatering→CNG Product	
CNG supply process	CNG Product →filling station→tankers→regulation station/ filling stations→	→Town gas network → end-user
		→CNG vehicles

B. Comparison between CNG and LNG as vehicle fuel

The main purpose of LNG and CNG is to be used as clean alternative fuel for urban public transport system vehicles. As shown below, compared with gasoline, diesel and LPG cars, they are obviously superior in terms of environmental protection, economic or safety. As technology options for CMM utilization, the selection of LNG or CNG should be considered in combination with the province's gas supply situation, economy efficiency of the two types of fuel, safety, emission reduction benefits, complementary of energy, technology standardization level and other factors to make comparison.

CNG is more popular as vehicle fuel in domestic promotion and applications than LNG, and the related technology and standards are more sophisticated. In Guizhou Province, Guiyang City’s transit system (bus) uses LNG as fuel, while Zunyi city uses CNG as taxi fuel.

Table 22: Comparison of major vehicle fuels (based on Guizhou context)

	CNG	LNG	93 # gasoline	0 # diesel
Gas source security	Poor	Poor	Better	Better
Emission Reduction	Good	Good	Poor	Poor
Price stability	Stable	Stable	Poor	Poor
Unit price*	5.0 Yuan / Nm^3	3.5 Yuan / Nm^3	7.65 Yuan	7.43 Yuan
Taxi fuel consumption per hundred km *	$10Nm^3$	$9.5Nm^3$	10L	8L
Taxi fuel cost per hundred km (Yuan)*	50	33.25	76.5	59.44
Technology maturity	Mature	Basically Mature		
National standards	Perfect	Has not been established		

Note: *CNG price is based on the reference price for CNG vehicles in Zunyi City, Guizhou Province in 2011. Gasoline, diesel prices are based on those of Guiyang City in 2011. Because

LNG has not being put to retail, the price refers to the internal settlement price of LNG in Guiyang Public Transportation Company in year 2010.

5.0.2.4 Gas concentration and purification

In accordance with state regulations, gas with concentration of less than 30% can't be put directly into the gas tank. First, it has to be concentrated and purified to raise the methane concentration over the range of explosion, and then stored in tank to be controlled and regulated, so as to create condition for mass industrial production of CNG, LNG or other products in the downstream.

There are three ways to improve gas concentration: First, it can be started from the source in improving underground gas drainage standards in order to avoid the need of high investment of equipment in gas purification. This will not only improve the quality of drained gas, but also improve the safety of mines. Secondly, the low concentration gas from gob and high concentration gas from pre-draining area can be mixed to obtain the most suitable concentration.

Here is the third way. The drained gas is purified through physical and chemical methods, and removed impurities (oxygen, nitrogen, carbon dioxide, carbon monoxide and hydrogen sulfide) through filtration, to obtain high concentration gas. Because the purification system is generally expensive, so before system installation, different technical options need to be evaluated to weigh the cost of and profit to fit the project's objectives. Currently in China, the major gas purification processes include two technical routes, adsorption purification and cryogenic separation purification. Please see the table below for details:

Table 23: Comparison of low concentration gas purification means and methods

Purification method	Process method	Advantage	Weakness
Adsorption	Pressure swing adsorption (PSA)	Methane has higher recovery rate and can maintain continuous operation	Limited to de-nitrification, cannot effectively adsorb other impurities
	Molecular sieve adsorption (MSA)	A variety of different adsorbents can be used to filter impurities; less methane losses	The efficiency of de-oxygenation needs to be improved; the cost is high

Cryogenic separation	Direct cryogenic separation		Device's energy consumption is high; methane recovery rate is limited; there are safety risks
	Catalytic liquefaction of oxygen separation	Process has been tested to be safer	Process is complex; operating cost is high; the requirements over concentration of methane is higher; methane recovery rate is low
	Solution absorption, de-oxygenation and separation		High cost, there is no economic value

Adsorptive purification and recovery of methane is currently the major method of gas purification and liquefaction, which include:

(1) Pressure swing adsorption:

In most of the pressure swing adsorption (PSA) de-nitrification unit systems, in each cycle of pressurization, large diameter carbon molecular sieves will preferentially adsorb methane. This process will recover methane-rich gas, and methane content will increase with each cycle. PSA process can recover up to 95% of available methane, and can be run continuously without paying special attention.

(2) Molecular sieve adsorption:

Molecular sieve adsorption (MSA) is a PSA process by utilizing an adjustable molecular sieve. The mesh of molecular sieve can be adjusted to 0.1 angstroms. If used to process inert gas with content of more than 35%, the cost will be high. Adsorption separation uses different adsorption rate on adsorbent for different adsorbate, to absorb different gases to achieve the purpose of gas separation. For CMM, we firstly need to work out a special adsorbent that will adsorb oxygen effectively from CMM, to achieve the purpose of removing oxygen.

The above two adsorption methods have the advantage of very small loss of methane in the separation process; this allows for full recovery of methane. The core problem of these methods is that they must develop special adsorbent for efficient adsorption of oxygen (not adsorb methane), and specific adsorbent for efficient separation of nitrogen and methane.

Cryogenic separation method uses a series of heat exchangers to liquefy high-pressure gas that is inputted. Compared with other purification techniques, cryogenic separation technology is able to maximize recovery of methane, with recovery rate of up to 98%. However, due to its high cost, it is more suitable for large-scale projects. This method is divided into:

✧ **Direct cryogenic separation:**

Because CMM contains oxygen, it is possible to change the concentration of gas as well as explosive range, so the method to compress gas for preparation of CNG is subject to certain restrictions. For safety reasons, low temperature media can be used firstly to indirectly refrigerate and liquefy CMM. Because methane's liquefaction point is higher than nitrogen and oxygen, methane in CMM is first liquefied; this will achieve the purpose of CMM liquefaction and recovery. However, due to the use of indirect liquefaction, and methane has a certain vapor-liquid equilibrium at a certain temperature and pressure, so the energy consumption is high for this method of methane recovery. Also, methane recovery rate is subject to certain restrictions due to gas-liquid equilibrium. Meanwhile, with continuous liquefaction of methane, the methane content remained in gas will gradually decrease, causing its concentration to reach into explosive range. As a result, there are safety problems by using this method.

✧ **Cryogenic methane recovery after catalytic deoxygenation and liquefaction**

By this method, oxygen in gas is removed by catalytic oxidation process, and methane is cryogenically separated and recovered, which can effectively avoid unsafe factors in the recycling process. This catalytic oxidation method has gone through process tests with good results. However, this method also has some economic problems, represented mostly in:

- After gas goes through catalytic oxidation, the oxygen content is very low. But in the high-temperature catalytic process, a lot of carbon dioxide will be produced, accompanied by some hydrogen and carbon monoxide, which bring a lot of impurities into the process of purification and cryogenic separation of methane. These impurities need to be removed one by one, so the whole process flow is long, and operating cost is high.

- The process of catalytic deoxidation is actually the reaction between oxygen and methane, so a lot of methane is lost in the process, resulting in a lower recovery rate for the whole device. For the steam produced in the process of catalytic deoxidation, it cannot be utilized due to geographical isolation.

- For catalytic deoxidation, when the proportion of oxygen and methane reaches certain extent, it is meaningless recovering methane after the reaction between methane and oxygen, so methane content in the gas has to meet certain requirements.

✧ **Recovery of methane by solution absorptive deoxygenation**

Catalytic oxygen deoxidation will consume a certain amount of methane, resulting in a lower methane recovery rate. Currently, some domestic institutes are working on adsorptive deoxygenation by solution. In theory, this method does not consume methane, and is expected to improve the methane recovery rate; but so far, for solution absorptive deoxygenation, due to high energy consumption in absorbing solution regeneration, and high operating costs in recovery of methane, its utilization still lacks economic value.

Presently, there are some projects of CMM purification and preparation of CNG / LNG in China that are put into commercial operation: In Qinshui County of Shanxi Province, since 2003, there are five CNG refilling stations are built one after the other, with construction size of 700,000 m^3 / day. The product is transported to Jincheng, Changzhi, Linfen, Linzhou, Anyang, Puyang, Jiaozuo, etc., for urban living, gas boiler, bus, taxi.[12]. The Songzao coal mine in Chongqing is building a large project using CMM for production of LNG / LNG, and is expected to put into operation in 2011. The project will be China's first CMM purification and LNG preparation project that is put into commercial operation. In the next few years, with maturity of the gas purification technologies, and improvement of quality of gas supply, gas purification and preparation of CNG / LNG will face a big market.

5.0.3 Initial evaluation criteria for gas utilization options

Before evaluation of gas utilization methods, it is necessary to make a brief description of our evaluation criteria to be used. There are three main purposes in CMM drainage and utilization: first is to promote safety in production; second is to access new energy, so as to improve the overall exploitation and utilization efficiency of coal resources; and third is to reduce greenhouse gas emissions and to protect the atmosphere. The following evaluation criteria will help us consider and compare alternative options regarding their progress in achieving the above purposes in the implementation process.

5.0.3.1 Financial efficiency evaluation

For evaluation of economic benefits of gas utilization options, we should first consider the content for conventional financial evaluation; the selection of specific metrics may be determined in discretion. For example, cash flow can include all fixed assets investment costs, variable investment costs (such as labor, fuel, operation and maintenance and other items) and income from product sales, etc.; for internal rate of return (IRR), the project's internal rate of return (i.e. full investment approach, without considering financing sources and terms) can be considered, or equity investors' internal

[12] Refer to http://www.jconline.cn/Contents/Channel_4433/2009/0615/229169/content_229169.htm

rate of return (i.e. capital fund method, considering the amount and cost of own funds and debt financing).

When doing financial evaluation, special consideration should to be given to some of the project-specific parameters and their impact on project financial indicators for gas utilization projects, such as variability of gas supply and concentration, opportunity cost and financing channels for alternative gas utilization options. In addition, the economic benefits of gas utilization project depend largely on the value of sales of project products and related incentives (such as emission reduction credits or subsidies), which is in need of special consideration.

Usually, when evaluating a gas utilization project, the carbon emission reductions generated by the project are assumed to be able to bring about income. In the pre-feasibility study, we did not consider the economic benefits brought about by carbon emission reductions generated in the project. It means that the benefits of CDM (Clean Development Mechanism) or any VER (voluntary emission reduction) are not included in the project's economic evaluation. We do this for the following reasons:

1. Although China has successful CMM utilization CDM projects, and has obtained regular income through carbon emissions trading, the success rate is still relatively low. Of particular note is that for the Guizhou CMM Utilization Project, as of writing this report, there is no CDM project being successfully registered, not to mention certification and trading of carbon emission reduction.

2. The "Kyoto Protocol" is about to expire, and the international community has not reached an agreement for the future of CDM. In this case, making carbon emissions reduction as a source of income to be included in the feasibility study is not convincing, but can be examined at a later date.

5.0.3.2 Social benefit evaluation

Gas utilization will not only bring direct economic benefits for the mine owners, its wide range of social and economic benefits are also very obvious. These are important aspects that need to be considered in evaluation of gas utilization options. CMM utilization will not only improve production safety of coal mines and reduce greenhouse gas emissions, it can also alleviate the current energy shortage, improve energy structure, and keep in line with national industrial policy requirements to develop a resource-saving and environment-friendly society.

For example, with rapid progress of China's industrialization and urbanization, as well as increasing popularity of cars, China's demand for energy increases rapidly. The rapid expansion gap between supply and demand of domestic oil and gas will provide many opportunities to CMM development in southwestern China, especially in Guizhou Province. CMM is the most practical and reliable alternative energy source in composition of China's conventional natural gas. Development and use of CMM is of great significance in easing tension on supply of conventional oil and gas, improving and optimizing energy structure, implementation of national strategies for sustainable development, reducing dependence on imported natural gas, and ensuring national energy security etc. Also, the construction and operation of gas utilization project will provide more local employment opportunities and promote local economic development, therefore serving the society.

5.0.3.3 Evaluation of emission reduction and environmental benefits

Methane is a greenhouse gas. CMM’s greenhouse effect is 21 times that of carbon dioxide. It is calculated that for every 100 million cubic meters of methane being used, the emission reduction is equivalent to 1.5 million tonnes of carbon dioxide. In 2008, China used 1.6 billion cubic meters of CMM, and reduced emissions 24 million tonnes CO2 equivalent. However, most CMM is discharged directly; this not only wasted resources, but also pollutes the environment. Improving gas utilization and minimizing gas emissions will help reduce air pollution and protect the environment. For example, Guizhou’s unreasonable coal-based energy structure and poor combustion technology not only waste a lot of energy, but also generate serious pollutions of sulfur dioxide, dust, nitric oxide, and mercury in urban environments. If CNG or LNG (both LNG and CNG) originated from coal source is used, the proportion of coal in energy consumption structure will see significant decline. This will improve the ecological environment, and keep in line with the strategic positioning of eco-development in Guizhou.

For different gas utilization ways and options, the methane consumption, replacement of fossil fuels or thermal power, leakages and project’s own emission levels will vary, and their baselines are different, so it is not easy to accurately measure their benefits on emission reduction. The CDM Executive Board of the United Nations has provided a set of related methodologies as guidance for quantitative evaluation of emission reduction benefits. With constraints on data and time, the report only did a rough evaluation of emissions reduction and environmental benefits of alternative options, and is not intended to make accurate quantitative estimates.

It is worth mentioning that, according to the logic of "promote draining through utilization", expanding the scale of gas utilization is a strong push to gas draining: thus in a sense, it can be said that at the gas utilization terminal, gas usage (emission reduction) volume is a measure of the environmental benefits of the project; while at the gas source, the amount of gas drainage can be regarded as indirect risk reduction measure for mine safety.

5.0.4 Pros and cons of alternatives of coal mine methane utilization

The table below classifies all the alternatives of coal mine methane utilization for Zhongling coal mine and compares their merits and faults. In Decision on Amending Some Provisions of Coal mine Safety Regulation, which was issued on March 1^{st} 2010, the requirement for utilizing gas with concentration of less than 30% is relaxed. All the options listed in table below do not encounter any policy and regulation obstacles; in fact they all comply with national industrial policies and are the targets for preferential policies.

Based on comparison of different alternatives, taking account of the actual situation of Zhongling coal mine, gas power generation or LNG production from gas should be the most reliable and feasible way of utilizing coal mine methane.

Table 24: Pros and cons of alternative utilization options

Option identification	Option description	Pros and cons	
Option1 **Coal mine methane power generation**	Scale of existing gas power plant is expanded to maximize the use of gas drainage volume which is increasing with coal production. In addition to replace electricity purchased from China Southern Power Grid, produced electricity can also be sold to the grid; waste heat can be recovered and used by boilers for plant area heating.	Pros	This is a good option in terms of small investment and quick returns and reliable technologies; waste heat from power generation process could be recovered and provided for domestic heating in mining areas as well as the heating and cooling in shafts. Electric generators made in China are suitable for coal mines in Guizhou as they are functionally reliable and financially acceptable; besides, they have complete specifications and low requirements for drainage system.
		Cons	*Electricity generated is mostly used for the production in the coal mine. However, with the gradual increase of energy efficiency, demand for in-house electricity is limited; local climate in Guizhou also results in limited demand of waste heat recovery in coal mines. In addition, because of the small scale of power generation and unstable working conditions, barriers exist for CMM power plant to send power to the grid. Therefore, the scale of power generation is difficult to be expanded; the 'promoting draining through utilization' strategy lacks the steam for implementation. Further, domestic low concentration gas generators have low efficiency; it is not the most optimal way for highly efficient conversion and utilization of coal mine resources.*
Option2 **Direct feeding into gas pipeline**	The drained coal mine methane is fed into pipelines and tanks for direct domestic use, district heating and industrial boilers. Coal mine methane with low concentration is vented into air directly.	Pros	This option has advantages such as low cost of fuels, good regional socio-economic benefits and less restrictive requirement for purification of gas supply.
		Cons	*One of the disadvantages is the high cost of transporting system and maintenance: auxiliary facilities of gas storage and peak shaving need to be constructed to deal with the fluctuation of gas concentration and volume as well as the demand in peak gas period. In addition, scale for domestic use is small, the gas is basically provided within the plant area as welfare, and the coal mine does not have motivation because of no economic profits. Particularly, the national concentration requirement for gas feeding into tankers must be higher than 30%, which cannot be met by most coal mines.*

Option3 **Producing LNG/CNG after purification**	Drained coal mine methane is purified through appropriate methods to produce LNG or CNG which, shipped outbound by tankers, is used as vehicle fuel for public transport system or as industrial fuel or raw material (e.g. Manufacturing carbon black, formaldehyde, synthetic fuel and dimethyl ether). Coal mine methane with low concentration could be used for power generation or vented into air.	Pros	This alternative fills in the gap of pipeline gas supply; the areas which are close to the pipeline system but not covered by are the highly preferred market for LNG/CNG. It has features as long industrial value change, wide end use purposes, huge profit-making possibility and great potential for improving local environmental protection and energy safety.
		Cons	*Disadvantage include: complicated technologies which result in high learning investment; high cost in terms of production, processing, storage, transport and pressure regulating; demands of importing some purification and liquefying devices. Also, as the industrial chain is long and cost of trading and cooperation is high, the public transport sector and transport companies should be negotiated with for modifying vehicle engines and transporting LNG/CNG outbound respectively. Moreover, technical standards for some application area have to be improved, new energy market has not been fully developed, and potential competition exists for long distance transport of CNG.*
Option4 **Combination of option1,2 or 3**	Coal mine methane is rationally allocated, based on the concentration, among above options. For instance, high concentration gas, after purification, is fed into pipeline or produce LNG/CNG for downstream industries as fuel or material; low concentration coal mine methane is used for power generation or vented directly.	Pros	The efficiency of coal mine methane utilization could be increased by optimizing the use of coal mine methane of various concentrations in different options. For instance, the huge electricity consumption needed by coal mine methane purification and LNG/CNG production can be provided by gas power generation plant, which can simultaneously release the pressure of on-grid power generation.
		Cons	*The disadvantages of this option are the high managerial cost for multi-usage and huge initial investment. In addition, complicated internal and external relationships have to be coordinated (such as the different demands of the power generation plant and LNG/CNG plant).*

5.1. Option of power generation and electricity sales

To discuss the feasibility of efficiently using drained gas by expanding the capacity of power generation, the project's implementer (GZICCEP) commissioned the coal industry experts of Hefei Coal mine Design Institute to develop an evaluation report. Analysis in this chapter is made according to the data, as well as economic and technical parameters in the report.

5.1.1. Technical option

The principles for choosing the scale of gas power generation units are: defining the capacity of the generating units which can work simultaneously according to available drained gas volume, increasing the number of stand-by units by considering the annual working hours of the units.

The distances between each of the 3 draining sites are far; it is at least 5km from Area 11 to Area 12 with a valley in between, it is unlikely to centralize the gas supplies altogether. Although the distance between Area 11 and Area 12 is about 1 km, as pressuring coal mine methane is not permitted by relevant requirements on transporting low methane concentration gas, and the long distance transporting has high resistance and risks, the power generators should be installed at each area separately.

According to the Design Specification of Safety System for Transporting Pipelined Low Concentration Coal mine methane (AQ1076-2009) issued by State Administration for Work Safety, coal mine methane with the concentration between 3-30% is defined as low concentration gas. Based on this specification, gas balance between drained gas volume and installed capacity is shown in the following table.

Table 25: Gas balance of Area 11 in 2010 and 2011

Years	2010			2011
Item	Maximum	Average	Minimum	Average
Volume (Nm^3/min)	44.49	7.68	3.61	27.00
Capacity that can be installed（KW）	6951	1199	564	4219
Capacity of existing generators (KW)	2000	2000	2000	2000
Total capacity to be installed（KW）	4951	0	0	2219

Number of 500KW generators that can be run simultaneously	9.9	0	0	4.4
Number of 800KW generators that can be run simultaneously	6.2	0	0	2.8
Standard pure gas consumption per kilowatt-hour is 0.384Nm^3/kWh (efficiency is about 26%). Amount of drained gas in 2011 is calculated according to the design of coal mine.				

Table 26: Gas balance of Area 12 in 2010

Years and mining area	2010		
Item	Maximum	Average	Minimum
Volume (Nm^3/min)	60.27	31.03	12.26
Capacity that can be installed（KW）	9417	4848	1916
Capacity of existing generators (KW)	3000	3000	3000
Total capacity to be installed（KW）	6417	1848	0
Number of 500KW generators that can be run simultaneously	12.8	3.7	0
Number of 800KW generators that can be run simultaneously	8.0	2.3	0
Standard pure gas consumption per kilowatt-hour is 0.384Nm^3/kWh (efficiency is about 26%).			

Table 27: Gas balance of Area 21 in 2010 and 2011

Years	2010			2011
Item	Maximum	Average	Minimum	Average
Volume (Nm^3/min)	30.72	18.80	10.96	29.00
Capacity that can be installed(KW)	4800	2938	1712	4531
Capacity of existing generators (KW)	2500	2500	2500	2500
Total capacity to be installed（KW）	2300	438	0	2031
Number of 500KW generators that can be run simultaneously	4.6	0.9	0	4.1
Number of 800KW generators that can be run simultaneously	2.9	0.5	0	2.5

Standard pure gas consumption per kilowatt-hour is 0.384Nm^3/kWh (efficiency is about 26%). Amount of drained gas in 2011 is calculated according to the design of coal mine.

Table 28: Gas balance of Area 12 in 2010, 2011 and 2012

Predicted year of gas in No. 12 mining area	2010	2011	2012
Volume (Nm^3/min)	1729	1602	1602
Capacity that can be installed (KW)	4848	4844	4844
Capacity of existing generators (KW)	3000	3000	3000
Total capacity to be installed (KW)	1848	1844	1844
Number of 500KW generators that can be run simultaneously	3.7	3.7	3.7
Number of 800KW generators that can be run simultaneously	2.3	2.3	2.3
Standard pure gas consumption per kilowatt-hour is 0.384Nm^3/kWh (efficiency is about 26%).			

Analysis is made as follows based on the above tables:

Half the time in 2010, gas concentration in Area 11 is lower than 10% (please refer to figure 4); however, the current minimum concentration requirement for low concentration gas power generation units is 7-9%. Half of the amount of gas emitted could not meet the minimum concentration requirement. In addition, the drainage is not stable; drained volume in 2010 is only 28% of the projected volume. Furthermore, drainage after 2011 is still uncertain, so Area 11 is not recommended for increasing the number of generators.

Comparatively, gas drainage volume in Area 21 is more close to planned volume (66%) than that in Area 11, but the average concentration in 2010 was even lower than that in Area 11; concentration of much of the coal mine methane could not comply with relevant concentration requirement for generators. Therefore, power generation in Area 21 is not recommended for expansion either.

In Area 12, gas concentration in 2010 was stable at more than 10%, and the volume is sufficient. According to the gas balance analysis, power generation in Area 12 can be expanded. Existing power generation units are domestically produced; site investigation shows that those units only operate less than 5000 hours per year. There are 8760 hours per year, and the expansion scale in Area 12 is defined as 4 sets of 500KW units. When gas volume is not sufficient they could be the stand-by units for original units. If calculated on the basis of 5500 operational hours per year and 0.384 Nm^3/kWh of gas consumption, electricity generated will be 11million kWh. Deducting in-house electricity consumption, 9.856 million kWh could be delivered to external market, eventually leading to gas emission reduction of 4.224 million m^3.

For normal operation of gas power generators, a series of auxiliary devices should be equipped, including a gas system, air system, smoke exhaust system, cooling system, lubrication system, crankcase respiratory system, power system and control system. All these systems are assembled and supplied by the combustion engine manufacturer.

Zhongling coal mine has a 35kv power substation. Area 12 is close to superior 6KV substation, so they are connected by one loop of 6KV cable. The final access scheme will be confirmed by the design of access system by the electricity sector. After operation, although electricity generated is not able to solve the problem of electricity shortage in Guizhou, the power tension in Zhongling coal mine can be effectively alleviated.

5.1.2. Financial analysis

The following section lists the parameters and assumptions for economic evaluation. The evaluation results are concluded in following sections.

5.1.2.1. Parameters input and assumptions

The following table shows the major parameters on which financial analysis is based.

Table 29: Financial analysis of gas power generation option: major data and parameters

No.	Item	Unit	Value
1	Number of generators	set	4
2	Power of single generator	kW	500
3	Annual working hours of generators	h	5500
4	Annual power generation when reaching designed capacity	GW·h	11
5	Electricity sales price (Excluding VAT)	Yuan/ kWh	0.51
6	Annual consumption of gas (100%)	10^4m^3 / a	422.4
7	Coal mine methane (100%) price	Yuan/ m^3	0.20
8	In-house electricity consumption	%	10.4
9	Composite depreciation period	a	10
10	Residual value	%	3
11	Amortization of other assets	a	5
12	Maintenance rates	%	2.5
13	Water consumption	T / h	2
14	Water cost (Excluding VAT)	Yuan/ t	1.20
15	Staffing	person	12
16	Per capita wage	Yuan/ Person-years	50000
17	Materials fee	Yuan/ MW.h	20
18	Other costs	Yuan/ MW.h	15
19	Output tax rate for Sale of electricity	%	17
20	Urban maintenance and construction tax	%	5
21	Education surtax rates	%	3
22	Income tax rate	%	25
23	Reserve fund escrow rate	%	10
24	Construction investment loan	%	6.80
25	Working capital loan interest rate	%	6.31
26	Financial benchmark rate of return	%	7.5
27	Calculated period of economic evaluation	a	11

5.1.2.2. Prediction results

The expected financial performance for implementation of the option is as follows:

Table 30: Results of financial analysis for gas power generation option

No.	Index Name	Unit	Index
1	Financial internal rate of return of investment (after tax)	%	6.04
2	Financial net present value of investment (after tax)	ten thousand	-113
3	Investment payback period (after tax)	years	8.53
4	Financial internal rate of return of investment (before tax)	%	7.79
5	Financial net present value of investment (NPV before tax)	ten thousand	23
6	Investment payback period (before tax)	years	7.92
7	Financial internal rate of return of project capital (after tax)	%	6.13
8	Total investment rate of return	%	4.66
9	Net profit ratio of project capital	%	6.99
10	Annual average after-tax net profit in years of production	ten thousand	38

All the key parameters in the table above show that this option has very poor profit-making ability: financial internal rate of return (after tax) is 6.04%, lower than the benchmark rate of return; financial net present value of investment (after tax) is a minus value; investment payback period (after tax) is 8.53 years; and the total investment rate of return and net profit ratio of project capital is respectively 4.66% and 6.99%. All these figures show that this option is not acceptable from the perspective of making profits.

In addition, in the assumed loan payback period (7 years), provision of interest rate in repayment period is 1.02-3.97, annual provision of interest rate in each year of repayment period is more than 1; in the repayment period, debt-servicing provision rate is 0.89-1.02, and annual debt-servicing provision rate in each year is less than 1. In order to pay all the loan in the defined loan payback period, short-term loan needs to be raised. All these implicate that the solvency of this option is weak.

Next, the cash inflow and outflow generated in the investment, financing and operation of this option are examined in order to calculate the net cash flow and accumulated surplus, which could facilitate the understanding of whether or not this option has sufficient net cash flow to maintain normal operation. An analysis of the cash flow statement shows that although annual net cash flow in each operation year is ≥0, it is relatively small, indicating that this option is not financially viable.

5.1.3. Risk analysis

The risk of project implementation is grouped into operational risk and financial risk, which are assessed respectively.

5.1.3.1. Operational risk analysis

The following table shows the qualitative assessment of foreseeable operational risks in the process of implementation of this option, and elaborates the counter-measures for high risk factors.

Table 31: Risk factors and counter measures

Risk Factors	Rating	Risk Description/ *Counter measures for high-risks*
Market risk		
Electricity sold to the grid	High	*Increase self-consumption of electricity. Allegedly, there are power supply shortages in mining area; and the demand in power generation market is great. The existing generators and the proposed addition of generators will basically meet the electricity demand within mining area. Thus, the role of mitigation measure is limited.*
Receive subsidies on grid feed-in tariff	High	The state issued a series of preferential policies to encourage and support gas drainage and utilization projects, including grid feed-in subsidies, but in few cases the subsidies are in place. *It is better for the enterprise to consume the electricity generated instead of purchasing from the grid.*
Gas supply security risk		
Gas supply shortage	Low	The coal mine has large gas reserve, if the coal production could reach the designed capacity, more gas supply will be guaranteed.
Unstable gas concentrations	High	*Measures must be taken to improve the drainage system.*

Gas supply costs	Low	Once the price of gas supply is determined, it’s unlikely to be changed: after all, gas have to be drained in coal mines.
Technological risk		
Reliability of power generation equipment	Low	The project uses proven domestic technology that is featured by advancement, reliability, and applicability. The chance of significant changes is slim.
Appropriate equipment management and maintenance in place	Low	Staff training is enhanced, and special personnel for management are designated.
Environmental and safety risk		
Gas explosion	Unknown	Three fire-arresting and anti-explosion devices with different principles are installed according to design specifications: water-sealed flame arrester, automatic anti-explosion device, water mist delivery device. In order to reduce costs, highest configuration is not used. Employee safety education and training levels are unknown.
Dust explosion and spontaneous combustion	Low	The geological report identifies that there is no risk of dust explosion and spontaneous combustion in each seams of the mine.
Pollution, noise	Low	Project construction will strictly abide by national emission standards. The production site has a comprehensive sewerage system. There is no resident living around, and there is no sensitive noise sources
Geological disasters	High	Complex geological conditions and human activities developed the possibility of geological disasters.
Financing risk		
Fund-raising capacity	Medium	The coal mine is not the subject for investing the construction of gas power station; there is a difficulty of financing from the third party.
Policy risk		

Supporting policy is not in place	Medium	Using gas drained from mines for gas power generation is in line with national industrial policies, but many preferential policies are not fully implemented.
Operational and collaborative risk		
Collaboration in construction (such as land disputes)	Low	The proposed site is located in the original plant site of the coal mine, and will not involve land acquisition, demolition, resettlement of residents, etc. Conditions in proposed construction site convenient.
Operational collaboration	Low	。 Water, electricity, fire control, staff management and off-site roads can depend on facilities of existing gas drainage station.
Collaboration in electricity sales	High	Due to reason of grid technology and economy, for gas power generation, effective grid feed-in agreement can’t be reached with local grid.
Collaboration in water and electricity supply	Low	As less water is needed for expansion, nearby water supply is sufficient and pipelines are available, water supply for mines is guaranteed. Electricity supply is reliable because of Nayong power plant and several substations.

5.1.3.2. Analysis of financial risks

Most of the data from the above financial evaluation is based on estimates, thus uncertainties are unavoidable. In order to assess the project's financial reliability, how the project’s financial performance changes according to fluctuation of key uncertain factors is examined; the endurance of the project is reviewed when these factors reach threshold values.

Four operational variables (electricity sales price, electricity sales, gas purchase prices and construction investment) which are vital to the economic benefits of the options are analyzed. The following table summarizes the impact on internal rate of return of the project when above variables changes by 10% and 20%. As the heat supply for this project is very small, it can be ignored in the sensitivity analysis. Sensitivity reflects a quantitative assessment of financial risks of the gas power generation option. The qualitative analysis of other operational risks is presented in the following section.

Table 32: Sensitivity analysis of financial assessment for power generation option

Variables	Magnitude (%)	Financial internal rate of return of investment (after tax) (%)	Sensitivity coefficient
Electricity sales price	+20	11.94	4.88
	+10	9.06	5.01
	-10	2.78	5.40
	-20	-1.09	5.90
Electricity sales	+20	10.50	3.69
	+10	8.31	3.76
	-10	3.63	3.99
	-20	1.06	4.12
Gas purchase prices	+20	4.94	-0.91
	+10	5.48	-0.93
	-10	6.55	-0.84
	-20	7.06	-0.85
Construction investment	+20	2.72	-2.75
	+10	4.25	-2.96
	-10	8.09	-3.39
	-20	10.56	-3.74

The above analysis shows that the project's risk resistance capacity is weak. This conclusion is also proven by break-even analysis: the break-even point calculated according to relevant data of the year when production reaches designed capacity is 99.23%; while the break-even point calculated by relevant data of the year when the loan of capital investment is paid off (8^{th} year of calculation period) is 79.23%.

5.1.4. Summary

The profit-making ability, solvency, financial viability and financial risk resistance of the option all receive poor assessment in the above analysis. In addition, the implementation of the option has to overcome huge operational risks in terms of grid feed-in power generation. Furthermore, the option aims at expanding gas power generation station in a single mining area rather than taking an intensive utilization of drained gas in the whole coal mine. All these factors will negatively influence the prospect of gas drainage and utilization in Zhongling coal mine, so the option is not recommended.

5.2. Purification and liquefaction of coal mine methane

This option aims to produce LNG by purifying and liquefying drained gas on site, and then transport LNG by tankers to downstream end users. This option is based on the consideration of the following aspects: Zhongling coal mine is located at a remote area but with relatively convenient transport and there are no gas pipelines nearby; long distance transport of LNG products has the advantages of reliability, few risks, high storage efficiency and good adaptability. CNG production from coal mine methane is not recommended because of the high transport cost, as Zhongling coal mine is more than 200 km away from the key markets of CNG, such as Guiyang and Zunyi. Furthermore, cold released from on-site purification process can be reused; some useful by-products from cryogenic liquefaction process can also be safely reused.

Gas supply is the surplus gas from Area 12. As Area 11 is close to the extraction pumping station in Area 12, when conditions are mature (concentration and volume of drained gas are increased and can comply with transport requirement), drained gas from Area 11 can be transported to Area 12 for treatment. However, as Area 12 is away from the pumping station in Area 12 and the transport conditions are complicated, surplus gas from Area 21 is suggested for on-site power generation instead of transporting to Area 12.

5.2.1. Technology and development options

Capacity of this project is 1560 Nm^3/h of raw gas, technology adopted is to liquefy recovered methane from coal mine methane through pressure swing adsorption (PSA) process, and the final product is LNG. This project chooses the technology of PSA recovery, which is developed by Sichuan Dakete Energy Science and Technology Ltd. The final product, LNG, is supplied to Guiyang, Bijie and Liupanshui as natural gas for vehicles, or directly sold to Guizhou Natural Gas Company. The gas purification and liquefaction technology of this company will be employed by Shanxi Ruiyang CMM Ltd. for its project of liquefying oxygen-contained gas to LNG (the annual capacity is 50 thousand tonnes of LNG). This project has an investment of 210 million Yuan and a total building area of 100 thousand m^2. PSA is used to deoxidize coal mine methane with 35% content of methane and freeze to -163℃, which is then purified and liquefied to LNG. Concentration of methane in the final product is above 99%. This project is under construction currently in Shanxi. In addition, Sichuan Dakete Energy Science and Technology Ltd. also provides the technology for two CNG purification projects in Sichuan Province.

LNG option includes 7 processes: gas pressurization, VPSA methane enrichment, methane-rich gas compression, deoxidation of methane-rich gas, liquefaction of deoxidized methane gas, LNG products storage and filling. Required water, electricity and steam are available from existing facilities.

Purification of coal mine methane normally requires methane concentration of more than 30%. Through communication with coal mine engineers, Zhongling coal mine is able to provide methane with the concentration of 25%, therefore raw gas for this option is based on 25% concentration. As the popularization of power generation units of low concentration gas, most coal mines have no motivation to increase gas concentration. Only when coal mine methane is purified to CNG/LNG, its value can be added up, and then the coal mines would be driven to increase concentration and volume of drained gas. The methane content in enriched LNG from raw gas is ≥98% (98% is the calculation basis); methane recovery rate for this project is 95%.

Considering the national LNG market and current gas drainage in Zhongling coal mine, the capacity and annual operation time of this project are defined as 11300t/a and 8000 hours respectively.

Key technical and economic indicators for this option are as follows:

Table 33: Major technical and economic indicators

No.	Indicators	Unit	Value	Remark
I	Production scale			
	LNG	Nm^3/h	1560.36	
II	Annual operational hours	hour	8000	
III	Consumption of key raw materials			
	CMM (25% methane)	ten thousandNm^3/year	6400	
IV	Utility consumption			
1	Water supply (fresh water)	ten thousand t/year	3.68	
2	Recycled water	ten thousand t/year	184.11	
3	Softened water	ten thousand t/year	0.00	
4	Electricity supply	ten thousand kWh	1513.43	
V	Floor space	m^2	0.00	undetermined
VI	Total investment	ten thousand Yuan	5835.29	

	Construction investment	ten thousand Yuan	5549.33		
	Working capital	ten thousand Yuan	150.00		
VII	Operating revenues	ten thousand Yuan	3744.86		
VIII	Annual gross profit	ten thousand Yuan	1352.32		
IX	Annual income tax	ten thousand Yuan	418.00		
X	Annual net profit	ten thousand Yuan	707.50		Excluding tax
XI	Financial indicators	ten thousand Yuan			
1	Annual average profit rate of investment	%	23.17		
2	Financial internal rate of return for investment	%	27	18.30	before/after tax
3	Payback period of investment (incl. construction period)	year	4.40	5.51	before/after tax
4	Break-even point	%	55.06		

5.2.2. Financial analysis

Based on market research and economic estimation, it is predicted that the project, upon its construction and operation, will be able to bring annual revenue of 37.46 million Yuan and annual net profit of 12.55 million Yuan.

5.2.2.1. Input parameters and assumptions

The table below presents key parameters for financial analysis:

No.	Item	Unit	Value
1	LNG sales price	Yuan/Nm^3	2.4
2	Construction period	month	12
3	Composite depreciation	year	10
4	Residual value	%	3%

5	Amortization of other assets	year	Intangible assets and deferred assets are amortized by 10 years and 5 years respectively.
6	Staffing	person	30
7	Per capita wage	Yuan/person·yea	50000
8	Materials fee	Yuan	Please refer to the table
9	VAT rate and others	%	13， Urban maintenance and construction tax and Education surtax is 5%
10	Reserve fund escrow rate	%	10%
11	Loan interest rate of construction investment	%	7%
12	Loan interest rate of working capital	%	7%
13	Financial benchmark rate for return	%	7.5%
14	Calculation period for economic evaluation	year	10
15	Income tax rate	%	25%

Table 34: Financial analysis of LNG option: key data and parameters

Table 35: Price list of raw material, power and auxiliary material

Material price		
No.	Raw material	Price (incl. tax)
1	Raw gas	0.05yuan/Nm^3
2	Nitrogen	0.2 Yuan/ t
3	Instrument air	0.15 Yuan/Nm^3
Power price		
No.	Power	Price (incl. tax)
1	Electricity	0.58 Yuan/kWh

2	Recycled water	0.1 Yuan/ t
3	Fresh water (replenishing)	2.0 Yuan/ t

5.2.2.2. Results

Financial performance of LNG option is predicted in the following table.

Table 36: Key financial indicators for LNG option

No.	Item	Amount
1	Construction investment (ten thousand Yuan)	5549.33
1.1	In which: RMB (ten thousand Yuan)	5549.33
1.2	Foreign currency (U.S. $)	0.00
	Converted to RMB (ten thousand Yuan)	0.00
2	Interest in construction period (ten thousand Yuan)	135.96
3	Working capital (ten thousand Yuan)	150.00
4	Total investment of project (ten thousand Yuan)	5835.29
5	Construction period (year)	1.00
6	Total production period (year)	10.00
7	Annual revenues of sales (ten thousand Yuan, year average)	3744.86
8	Total cost of annual sales (ten thousand Yuan, year average)	2392.54
9	Annual operating costs (ten thousand Yuan, year average)	1798.63
10	Annual variable costs (ten thousand Yuan, year average)	1236.97
11	Annual fixed costs (ten thousand Yuan, year average)	1155.57
12	Annual after-tax profit (ten thousand Yuan, year average)	1255
13	Annual VAT payments (ten thousand Yuan, year average)	273
14	Annual income tax (ten thousand Yuan, year average)	418
15	Total annual profit tax (ten thousand Yuan, year average)	1352.32
16	Profit and tax ratio of investment（%，year	23.17

	average)	
17	Profit ratio of investment (% , year average)	12.12
18	Capital ratio (% , year average)	7.08
19	Rate of return on investment (% year average)	19.28
20	Debt ratio (% , 1st year of normal production)	56.48
21	Mobility ratio (% , 1st year of normal production)	275.00
22	Quick ratio (% , 1st year of normal production)	132.20
23	Full investment after income tax	
23.1	Payback period of investment (year, static)	5.51
23.2	Financial internal rate of return (%)	18.3
23.3	Financial net present value (ic=7.5%,ten thousand Yuan)	2899.53
24	Full investment before income tax:	
24.1	Payback period of investment (year, static)	4.4
24.2	Financial internal rate of return (%)	27.0
24.3	Financial net present value (ic=7.5%,ten thousand Yuan)	5539.15
25	Break-even point (% , yearly average)	55.06

The table shows the pre-tax and after-tax financial internal rate of return of investment is 27.0% and 18.3%, both higher than the financial benchmark rate of return; financial net present value is above zero; static payback period (including construction period) is 5.51 years. Each key parameter indicates that this option has a satisfactory capacity in terms of generating profits.

Analysis of the project's Cash Flow Statement concludes that in each year of the production period, net cash flow from operation is above zero; meanwhile, the accumulated surplus fund over the years is positive and is increasing yearly, which shows this project is financially sustainable.

5.2.3. Risk analysis and control

The operational and financial risks for LNG option are analyzed qualitatively and quantitatively.

5.2.3.1. Operational risks

Potential risks of LNG are summarized below, covering several aspects including construction, operation and marketing.

Table 37: Operational risk factors and counter measures of LNG option

Risk Factors	Rating	Risk Description/ *counter measures for high-risk*
Market risk		
Alternative fuels competition	Low	LNG is more convenient, clean and safe than other vehicle fuels
Construction of gas filling stations	Unknown	
Vehicle modifications	Unknown	
Difficulty in LNG outbound shipping by tanker	Low	Convenient site traffic
Gas source security risks		
Gas supply shortage	Low	The annual gas drainage volume is stable.
Unstable gas concentrations	High	The purification devices in this project are applicable to methane gas of different concentrations. A variety of processes including gas separation and purification is adopted for methane recovery.
Gas supply costs	Low	
Technical risk		
Reliability of purification equipment and process	Medium	Technical staff can be trained to monitor the gas manufacturing flow, and maintain equipment.
Instability of methane concentration for CNG product	Low	
Environmental and safety risks		

"Three wastes" discharge	Low	Purification units don't produce gaseous pollutants in normal production; condensate generated is piped into sewage treatment system and does not discharged outside; discarded adsorbent and catalyst are recycled to suppliers.
Noise	Low	Special measures can be taken to control noise levels below environmental standards.
Safety risks (hazardous substances, electric hazards, etc.)	Low	The only safety risk is associated with methane and high- and low-voltage motors. Necessary measures will be taken to prevent the obvious and potential risk factors in production These measures will also be integrated into overall design in accordance with the norms, regulations, standards.
Financing risk		
Loan risks in construction period	Unknown	Coal mine has sufficient funds, but there is big shortage of construction capital.
Loan risks in operation period	Unknown	Working capital that is required to operate is not enough, and is in need of loans.
Policy risk		
Risk of policy changing	Low	The project conforms to relevant national policies, such as recycling economy, energy cascade utilization, cleaner production, continuous automation, and other environmental protection and energy saving measures.
Collaborative risk		
Collaboration in production and services	Low	
Transportation coordination	Unknown	Need to negotiate for outbound tankers arrangement with transportation company
End use coordination	Unknown	Need to negotiate with urban public

		transport companies regarding filling station construction and vehicle modification

5.2.3.2. Analysis of financial risks

The sensitivity analysis aims to assess the impact of four factors, including proceeds of sales change, production costs, fixed asset investment and construction period, of which their changes will influence the financial internal rate of return (FIRR) (after tax). The calculated results are shown in the table below.

Table 38: Results of sensitivity analysis

Variables	Magnitude (%)	Financial internal rate of return of investment (after tax) (%)	Sensitivity coefficient
LNG sales price	+20	28.4	2.76
	+10	23.5	2.84
	-10	12.8	3.01
	-20	6.7	3.17
LNG production	+20	27.6	2.54
	+10	23	2.57
	-10	13.3	2.73
	-20	7.8	2.87
CMM purchase prices	+20	17.4	-0.25
	+10	17.8	-0.27
	-10	18.7	-0.22
	-20	19.2	-0.25
Construction investment	+20	13.6	-1.28
	+10	15.8	-1.37
	-10	21.3	-1.64
	-20	24.9	-1.80

The above sensitivity analysis indicates that the most sensitive factors are LNG sales price and LNG production. Since LNG price is likely to remain stable, if not going up, it is important to maintain a stable LNG production, which is strongly associated with CMM drainage.

It is estimated the project will generate annual sales proceeds of 37.4486 million Yuan, while the annual costs of sales are 23.9454 million Yuan of which annual fixed costs are

11.5557 million Yuan and annual variable costs are 12.3697 million Yuan.

The break-even analysis proves the production capacity is 55.06% of designed capacity, when production volume is beyond the break-even point, profits will be realized.

5.2.4. Summary

The above analysis concludes that this project could receive good economic revenues while its risks are controllable. As the gas supplier, the coal mine has the motivation to improve gas drainage and sell drained gas. Project investors also could receive reasonable benefits, and therefore, the project has strong feasibility for implementation.

5.3. Comparison of end-use options

In this section, financial, environmental and social-economic benefits for both power generation option and LNG option are compared. Furthermore, an optimized option with complementary advantages of the two options is recommended for Zhongling coal mine.

5.3.1. Financial benefits comparison

5.3.1.1. Investment comparison

The comparative evaluation of project investment should include two aspects: technical and economic analysis and evaluation of the single technical scheme or construction investment scheme, and comprehensive technical and economic analysis, argument and evaluation of overall project construction investment scheme. The former has been introduced in 5.1.3 and 5.2.3 respectively; here, the simplified "cost - benefit analysis" method is adopted to compare the financial indicators associated with overall return of investment for the above two options, and examine the impact on the overall financial benefits with the change of key cost and return indicators in the period from construction to operation (service life) (see table below).

Table 39：Comparison of Investment returns between power generation option and LNG option

Indicator	Unit	Power generation option[13]	LNG option

13

Service life	Year	10	10
Budgetary estimate of fixed asset investment	Ten thousand Yuan	1805	5835.29
Working capital	Ten thousand Yuan	26	150
Break-even point	% , yearly average	99.23%*	55.06%
Financial internal rate of return of investment (after income tax)	%	6.04	18.3
Financial net present value of investment (after income tax)	Ten thousand Yuan	-113	2899.53
Payback period of investment (after income tax)	Years	8.53	5.51
Financial internal rate of return of investment (before income tax)	%	7.79	27.0
Financial net present value of investment (before income tax)	Ten thousand Yuan	23	5539.15
Payback period of investment (before income tax)	Years	7.92	4.4
* Calculation is made based on relevant data of the year when production reaches designed capacity.			

The above table shows that the power generation option has a negative financial net present value, indicating no possibility of making profits; while the same parameter for LNG option is much higher than zero, indicating better profit-making potential. In terms of financial internal rate of return, the LNG option has better profit-making potential than the power generation option. In addition, solvency and financial viability of the LNG option is much better than the power generation option. Competitive advantages for the power generation option are its lower initial investment cost and less requirement of working capital, as well as its lower financing costs.

5.3.1.2. Comparison of financial sensitivity

Sensitivity analysis concerns changes in key operating parameters of financial analysis within a reasonable range, the difference of impacts on the sustainability and stability of the overall economic performance, and whether the above conclusions on comparative financial analysis are still valid. That is, if the operating circumstance changes, what happens to the relative attractiveness of investment of each option.

Here, we examine the following common factors that will influence the internal rate of return of the two options:

1. Sales price (electricity sales price, LNG sales price)
2. Production (electricity sales to grid, LNG sales volume)
3. CMM supply prices
4. Construction investment

Assuming that the above parameters change within the range of -10% to +10%, the changes of internal rate of return for two options are listed in the following table.

Table 40：Financial sensitivity comparative analysis of alternative options

Variables	**Power generation**		**LNG**	
	Factors (Power generation)	Financial internal rate of return on investment after income tax (%)		Factors (LNG)
+20	Electricity sales price	11.94	28.4	LNG sales price
+10		9.06	23.5	
-10		2.78	12.8	
-20		-1.09	6.7	
+20	Electricity production	10.50	28.4	LNG production
+10		8.31	23.0	
-10		3.63	13.3	
-20		1.06	7.8	
+20	CMM purchase price	4.94	17.4	CMM purchase price
+10		5.48	17.8	
-10		6.55	18.7	
-20		7.06	19.2	
+20	investment	2.72	13.6	investment
+10		4.25	15.8	
-10		8.09	21.3	
-20		10.56	24.9	

5.3.2. Operational risk comparison

Table 41: Total number of risk factors and their ratings for alternative options

Power generation option	LNG option
Market risk	
High risk (1), medium risk (1)	Low-risk (2), uncertain (2)
Gas supply security risk	
Low risk (2), high risk (1)	High risk (1), low risk (2)
Technical risk	
Low risk (2)	Medium risk (2)
Environmental and safety risk	
Low risk (1), unknown (1)	Low risk (3)
Financing risk	
Low risk (1)	Unknown risk (2)
Policy risk	
Medium risk (1)	Low Risk (1)
Collaborative risk	
Low risk (3)	Low risk (1), unknown risk (2)

5.3.3. Comparison of environment and emission reduction benefits

Both options aim to utilize the drained CMM as the fuel to generate new energy, avoiding a direct large quantity of CMM emissions into air and aggravation of greenhouse effect. Therefore, at macro level, both options are environmentally-friendly.

Considering the production process, both options generate little air pollutants which can also comply with standards. Negative impacts on the environment do not exist and activities comply with permitted limits. Although the equipment noise is high, it can be mitigated largely by measures such as sound absorption, attenuation and insulation. In addition, noise levels at residential sites meet relevant requirements as the sites are away from the equipment.

Due to data constraints, we cannot make accurate comparative analysis regarding comprehensive environmental benefits of the two options. Based on the data in the pre-feasibility study report, we only make some rough estimates of greenhouse gas emission reduction potentials of the two utilization options, and take them as a reference to compare their emission reduction benefits. Here only the amount of gas consumed in project’s production process is considered; the gas is assumed to be completely vented in the baseline scenario. The actual energy consumption in the project's implementation, fuel substitution by project products (electricity and LNG) and other factors are not taken into account.

✧ Gas power generation option: In the current project phase, there are four 500KW power generation units. Calculated according to 5500 working hours per year and methane consumption rate of 0.384Nm^3/kWh, the annual electricity output can reach 9.856 million kWh, reducing methane emission 4.224 million m^3, which is equivalent to 60,319 tonnes of CO^2 emission.

✧ LNG option： Emission reduction of this option is calculated in the table below:

Formula	Equivalent CO2 emission reduction = CMM emission amount ×0.01428	
Item & coefficient	Explanation	Result
1.CO_2 equivalent (Tonne)	CMM consumed for producing LNG is converted into annual emission reduction.	218,427
2.CMM volume (m^3)	Pure methane consumption a year for producing LNG.	15,290,000
*Assuming that it has an annual capacity of processing 64 million Nm^3 of CMM (25% methane concentration) and operating time of 8000 hours, if the methane recovery rate is 95.6%, the result would be 64 million Nm^3×25%×95.6%=15.29 million Nm$^{3.}$		

It should be pointed out that whether the ‘emission reduction potential’ can be realized depends on the extent to which gas products can substitute energy in downstream industries.

5.3.4. Comparison of overall socio-economic benefits

The socio-economic benefits of both options are obvious: their objectives are aligned with the policies of developing a circular economy, energy conservation, cascade utilization and cleaner production; and they both can promote safety in coal mines and integrated utilization of coal resources through ‘promoting draining through utilization’ and ‘promoting mining through draining’. However, on the whole, the LNG option has better socio-economic benefits; for instance, its staffing quota is 30 persons while the power generation option has only 12 newly added staff, not to mention its positive impact on employment in downstream industries.

In the long run, the LNG option has more remarkable overall socio-economic benefits in aspects such as safeguarding national energy security through energy substitution, and increasing the added value of coal industries by extending the industrial chain and demonstrating emission reduction through trans-regional and multi-industrial cooperation. For instance, current LNG supply in the southern part of China is heavily dependent on imports; while many LNG import programs are suspended due to increasing international LNG price in recent years. On the other hand, new LNG programs are not permitted[16], leading to deficient LNG supply as limited LNG volume is produced in China. In this context, it is strategically significant for Guizhou province, a mountainous place with little resource of oil and gas, to produce LNG from coal mine methane, as the LNG option has the following advantages:

1. Cost of production and construction is relatively low. Coal mine methane barely contains any hydrogen, mercury and heavy hydrocarbon, and its production process is simple. Estimation shows that producing every cubic meters of LNG from CMM consumes 1.12-1.5 kWh of electricity and a little water. Automated production is now available in modern plants for CMM liquefaction. A plant with capacity of 500,000m^3/day needs less than 50 staff; whereas the unit cost of CMM liquefaction is about 0.6-0.7yuan/m^3. Comparing with those factories of Zhongyuan Oil Field in 1999, unit investment is reduced by more than 60% and operational cost by 20-30%. On the other hand, CMM liquefaction facilities have advantages such as smaller building scale than regular LNG facilities, flexible requirement of sites and controllable construction cost. Normally, large scale LNG projects for final users are normally required to link with LNG production.[16]

2. It is a vital supplement for pipeline LNG and can play a positive role during peak-shaving of pipeline gas. In 2009, LNG from CMM is an important energy substitution option in the 'gas shortage' in south China.

3. Construction is not subject to a gas pipeline system. Although the end-user market of LNG is the same with that of pipeline gas, it is relatively independent[16]. The development of pipeline gas has an established market for LNG from CMM, while LNG from CMM is a good supplement for pipeline gas supply. Areas which are close to but not connected to pipeline systems are the preferential market for LNG from CMM.

4. Energy use efficiency in production process is high. The cold released from the CMM liquefaction process can be recovered and reused, also the cold from the gasification process of liquefied CMM can be used for freezing and cryogenic grinding. Therefore, some peak shaving facilities and freezing enterprises can be constructed jointly. According to the current technology of CMM liquefaction, about 50% of the energy consumed can be recovered and reused.

5. The cost for long distance transport is relatively low. When liquefied and compressed, the volume is only 1/625 of that of CMM, which remarkably increases the efficiency and benefits of transport. The vehicle cylinder for LNG has advantages of low pressure, low weight and small amount. For one standard gas tanker of 35 m^3, it can transport 21 thousand m^3 of LCPM, equivalent to the production capacity of 10-15 vertical shafts. Within the distance of 1000 km, the unit transport cost is

about 0.7 Yuan/m^3.100km.

6. It is safe in terms of production and utilization. The ignition point of LNG is 650℃, about 230℃ higher than that of gasoline. The explosion limit is 4.7%-15%, 2.5-4.7 times higher than that of gasoline. The LNG density is about 0.47, while the gasoline density is 0.7. LNG is lighter than air. When leakage occurs, it spreads out and absorbs heat quickly, and is very unlikely to explode or self-ignite.

5.3.5. Feasibility of optimum use of gas

Data analysis of drained gas from Zhongling coal mine shows that only the No. 12 mining area has stable surplus gas to be used for low concentration power generation units, and even so, its economic profits are not promising. Either the gas concentration or volume in No.11 and No.21 areas is not enough for power generation. To make full use of drained gas in Zhongling coal mine, both the gas concentration and volume should be improved, which can not only secure mining safety but also create preconditions for optimum usage of gas.

In that context, surplus gas from Area 12 can be used to produce LNG. If the methane concentration of surplus gas at Area 11 is able to meet transport requirements (>30%), it could be transported via pipe to LNG production system at Area 12. If it is difficult to transport, the gas could be used for on-site power generation to provide electricity for LNG production. As Area 21 is too far away from Area 11 and 12, its surplus gas is recommended for on-site power generation.

5.4. Conclusion

Zhongling mine currently produces 1 million tonnes of coal a year. However, it drains more than 30 million m^3 of methane a year, almost 70% of expected gas drainage volume for an annual coal production of 3 million tonnes. When Zhongling mine reaches its designed capacity in 2015, we expect a significant increase of drained gas. With existing CMM, there is only 20% utilized through low concentration power generation. Constrained to sell electricity to the grid, the majority of existing CMM calls for an alternative utilization option. Through our pre-feasibility study, we recommend a full scale feasibility study to look at CMM-to-LNG option regarding existing and future gas resources in Zhongling mine.

Based on the above comparative analysis, additional preliminary conclusions are listed below:

1. Both options presented for the Zhongling mine - power generation and LNG – improve coal mine safety and reduce methane emissions to the atmosphere. But in terms of economic and technical evaluation, the power generation option is not feasible due to poor performance in profitability, debts repayment, financial viability

and anti-financial risks. In addition, there exist huge operational risks for power generation onto the grid. In contrast, despite a high initial investment, high financing costs and long payback period of investment, the long-term expected profit and investment return of LNG are both higher than that of power generation. From both the medium and long term perspectives, LNG has better overall economic and environmental benefits than the power generation option, with a promising development future.

2. The biggest operational risks of LNG implementation include negotiation with transport companies on transportation by tanker, with urban public transport companies on gas filling station construction and vehicle modification, as well as project financing. It is strongly recommended that the project developer starts consultation with stakeholders as early as possible and formulate measures for reducing collaboration risk.

3. Having built and managed CMM power generation plants, the Zhongling mine is familiar with CMM power generation techniques. It is easy to habitually follow those adept techniques. However, the low concentration power generation is unlikely the best option for CMM utilization due to its low efficiency of energy conversion and potentially unsafe working conditions. LNG produced from CMM is a technological innovation for Zhongling mine and has better market potential. Despite complexity of the technology and higher investment, CMM to LNG production seems worthy of investment with better returns.

4. The primary purpose of coal mine gas drainage and utilization is to promote coal mining safety. Guizhou is poor in oil and gas sources, but it has an increasing demand for natural gas. While it is difficult to provide CMM power generation to the grid, CMM purification for LNG could become an extension of the coal mining industry in Guizhou with huge market potential. It this way, the motivation of draining more and better quality CMM for LNG would be much higher than for power generation, thus improving mining safety significantly. In this regard, the option of CMM for LNG should be actively promoted in Guizhou.

5. Compared with gasoline, diesel and LPG vehicles, CNG vehicles have irreplaceable advantages in terms of environmental protection, economy or safety, and are also a more mature technology than LNG vehicles. However, LNG is much better in storage and refueling is faster than CNG vehicles. LNG is likely to compete with or even replace CNG in the future. Upon the provincial natural gas utilization plan ("gas from Sichuan into Guizhou," "gas from Myanmar into Guizhou"), development of a natural gas based vehicle industry in Guizhou is likely to unfold as follows: In the early stage, vehicle retrofit techniques for CNG-gasoline dual-fuel system are introduced to launch a natural gas vehicle market, and gas fueling stations are gradually constructed. The retrofit mainly focuses on gasoline buses and taxis (e.g.

Zunyi City). In the mid-term, CNG and LNG single fuel vehicles are introduced directly, such as in the Guiyang bus system. In the long term, with the introduction of LNG and the maturity of LNG technology, LNG as a fuel will be introduced to long distance buses (inter-city) and trucks to transport coal. To hold an invincible position in the increasingly competitive vehicle fuel market, Zhongling mine should pay more attention to the mid and long term market trends of switching oil to gas by public transportation in Guizhou.

6. To make good use of the drained CMM of Zhongling mine, both the methane concentration and volume have to be increased. This will not only improve mining safety but will also lay the foundation for optimizing gas use. With this foundation, surplus gas from Area 12 can be used to produce LNG. If the methane concentration of surplus gas at Area 11 is able to meet transport requirements (>30%), it could be transported via pipe to LNG production system at Area 12. If it is difficult to transport, the gas could be used for on-site power generation to provide electricity for LNG production. As Area 21 is too far away from Area 11 and 12, its surplus gas is recommended for on-site power generation.