Qinglong Coal Mine Methane Utilization Pre-feasibility Study Report

Guizhou International Cooperation Center

for Environmental Protection

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1.0 Executive Summary

The project is funded by the U.S. Environmental Protection Agency, and is implemented by the Guizhou International Cooperation Center for Environment Protection (GZICCEP). GZICCEP prepared a pre-feasibility study report of coal mine methane (CMM) utilization for the Qinglong coal mine, in order to promote full use of coal mine methane resources and reduce methane emissions.

Gu Li town, where Qinglong mine is located, is in the eastern part of Qianxi County, Bijie Prefecture of northwestern Guizhou Province. The coalfield has relatively convenient transportation: only 14 km to Qianxi County through Gui-Bi two-way inter-city road. The geological reserve of coal is 190 million tonnes and minable reserve is 89 million tonnes. Qinglong coal mine is designed to produce 1.2 million tonnes of coal per year. The mine is classified as a gassy coal mine. It has 2.85 billion m^3 of methane reserve, of which 1.34 billion m^3 methane is drainable. The coal mine gas drainage station installed two permanent surface drainage systems with a total of four extraction pumps. In 2009, the gas extraction volume is 11,275,000 m^3, with 3,427,188 m^3 used for power generation and 7,847,900 m^3 methane was vented. In 2010, the total volume of gas extracted increased to 16.22 million m^3, and the gas volume used for power generation was only about 5.11 million m^3. More than 11 million m^3 methane was vented. With respect to increasing volume of drained methane, the project studied and compared two gas utilization options: power generation and gas purification for CNG.

Coal mine Background

Qinglong Coal Mine is the first large-scale modern mine that is held, developed and constructed in Guizhou by Shandong Yanzhou Mining Group, specifically, developed and constructed by Guizhou Qianxi Energy Development Co., Ltd., a subsidiary of Yanzhou Mining Guizhou Energy and Chemical Industry Co., Ltd (referred to as "Yanzhou Guihua" in the following). Yanzhou Guihua 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.

Qinglong Coalmine is directly developed and constructed by the Guizhou Qianxi Energy Development Co., Ltd. The corporation was established in January 2004, and was jointly established by Yanzhou Mining Guizhou Energy and Chemical Industry Co., Ltd, Guizhou Zhongshui Energy Development Co., Ltd., Guizhou Qinglong Industrial Co., Ltd. and Guizhou Qianxi County Qianfa Coal and Electricity Investment Company, and funding ratio is 47%, 30%, 18%, and 5%.

Geology and Resources of Qinglong Coal Mine

The terrain of Qinglong coalfield is simple and relatively flat. The general trend of the terrain within the coalfield presents a pattern with high level of Southeast, and low level of Northwest. Qinglong Mine is located in Qianxi coal field. Within the minefield, there are 15 coal-bearing strata, in which there are 6 recoverable or partially recoverable coal layers, which are M2, M3, M9, M16, M17 and M18 from top to bottom respectively. Among them, M16, M18 are the major recoverable coal layers. M17 is a partially recoverable coal layer; M2, M3, M9 and others are partially recoverable coal layers. In the main coal-bearing strata, the total coal seam thickness is between 2.44 to 22.26m, with average thickness of 8.90m, and a coal bearing ratio of 10.1%. Qinglong coalfield has abundant gas resources, with gas reserves of about 2.85 billion m^3, and exploitable gas of about 1.34 billion m^3.

It is estimated that when Qinglong mine reaches its designed production in 2014, it will have 16.36 m^3/t of relative emission of gas, and 46.62 m^3/min of absolute emission of gas. According to actual extraction data, the current absolute emission is about 30-35 m^3/min. For high vacuum gas drainage system, the CMM concentration stays in the range of 24 to 30% over the long term; the net flow of CMM is between 18 to 20m^3/min (100% pure methane). For low vacuum gas drainage system, the CMM concentration remains in the range of 8 to 10% for long term; the net flow of CMM is between 12 to 15m3/min (100% pure methane). With continuous improvement of the drainage system and underground drilling techniques, the drainage efficiency of CMM will be gradually increased, and the amount of extractable gas will continue to increase, providing adequate CMM resources for utilization.

Qinglong Coal Mine currently has a gas power plant with 3400KW installed capacity. The units include respectively four 500KW (low concentrations CMM units), and two 700KW (high concentration CMM units). The CMM drainage and utilization status and prediction are shown in the table below.

Table 1. Statistics of Qinglong Mine's annual drilling data and gas utilization

Year	Coal mining output (t)	Drill site number	Drill hole number	Footage (m)	Drainage (ten thousand m^3)			Power generation (ten thousand kWh)	Gas utilization (ten thousand m^3)
					High vacuum	Low vacuum	Total		
2004	2542			40000			16		
2005	251656						446		
2006	140876		872	58050			437	444	171
2007	553066	288	1960	105145	471	177	647	504	194
2008	807800	254	2827	158644	509	256	765	882	337
2009	805318	149	3101	183498	575	552	1128	876	343
2010	1041425	186	4208	238236	966	656	1622	1362	511
2011	950000	200	5500	250000	1200	800	2000	1300	550

2012	1000000	220	5700	260000	1400	800	2200	1500	660
2013	1100000	250	6000	280000	1400	900	2300	1700	690
2014	1200000	260	6500	320000	1600	900	2500	1700	750
2015	1200000	280	7000	350000	1600	900	2600	1700	750

Note: data for 2011-2015 is estimated.

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.

Qinglong mine mainly supplies coal to the Qianxi Power Plant, located 19 km from the coal mine, with installed capacity of 1.2 million kilowatts (4 x 300 MW). The power plan was completed by the end of 2006 and its annual coal consumption is 3 million tons. In addition to Qianxi Power Plant nearby, the sales market of Qinglong coal mine includes Dafang Power Plant, which is about 70 km away from the mine. Dafang Power Plant's first phase has a generating capacity of 1.2 million kilowatts (4 x 300 MW), and was put into operation in November 2007, with annual consumption of anthracite coal of 3 million tons. In December 2010, the feasibility study report of Dafang Power Plant's second phase 2 x 660MW supercritical coal-fired unit expansion project was approved. The second phase is expected to operate in 2014, which will double the coal consumption of the power plant.

Based on the coal demands from local power plants, there is hardly concern about the market for Qinglong Coal Mine's coal. The only discouraging factor is the low price for coal, which is largely determined by the government instead of the market.

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.

Based on the interviews with Qinglong mine’s management, the above factors limit the initiative for the mine to utilize the excess gas by adding more power generation units. However, the coal mine does plan to add two more gas engines to meet its internal power demand. After that, Qinglong mine will be almost self-sustaining in electricity. Therefore, if Qinglong Coal Mine considers fully utilizing its CMM resource through power generation, it must realize grid connection and sell surplus power to the grid.

1.1 Gas utilization technology options

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.

In order to identify options for CMM utilization, we used the CDM "obstacle analysis" method and listed the practical and reliable technology options available for Qinglong mine for gas utilization. Different from the logic behind the CDM method, our aim is to investigate foreseeable economic, technical or operational obstacles in the implementation process for various options, rather than identify legal and regulatory barriers, because all the technologies listed are not faced with prohibitive barriers imposed by policy and regulations. Here, we classify the barriers of implementation into "general obstacles" (A) and "insurmountable obstacles" (B).

The result indicates that there are two options of gas utilization solution for Qinglong Coal Mine that are practical and feasible: gas power generation or preparation of CNG from CMM.

Power Generation Option

In Qinglong mine the existing CMM power plant uses both high- and low- concentration CMM. However, the mine management believes that the two high concentration gas engines ask for high quality feed gas, leading to reduced stability of power generation. Now the coal mine is considering converting these two gas engines into low-concentration units in order to increase the power generation capacity.

Qinglong mine currently has a gas power plant with 3400KW of installed capacity, including 4 units of 500KW (low concentration CMM), 2 units of 700KW (high concentration CMM). The extraction volume of methane in 2010 totals 16.22 million m^3, with only about 5.11 million m^3 used for power generation and 11 million m^3 methane emitted.

Based on this option, there will be eight 500KW low concentration gas engine units to be added, with four 500KW units to be added in this phase, setting aside expanding spaces for four 500KW generation units later. For the current project phase, the four 500KW power generation units will be operating 5500 hours annually, with annual power generation of 11 million kWh. Less the power needs for self-consumption, it has 9.81 million kWh for output to the grid.

The total investment of this option (4x500KW) is 17.96 million Yuan. The internal rate of return (IRR, after tax) of financial investment in this option is 8.56%, which is greater than the financial benchmark rate of return (7.5%) of power generation projects accepted in China. The financial net present value (NPV) of project investment is greater than zero. The investment recovery period (after tax) is 7.67 years. Total investment rate of return and net capital margin rate were 6.91% and 12.95%. These indicators show that the project profitability is not strong, but can be accepted.

According to analysis to this option's financial and operational risk, the project's financial risk-resisting ability is not strong. But the operational risk can be controlled. Taking break-even analysis for example, the break-even point is 89.43% when project reaches its designed capacity and 70.80% calculated when the loan for construction is paid off.

Based on the above analysis, coupled with significant operational risks of uncertainties associated with implementation of grid connection, this option is not recommended.

CMM to CNG Option

This option is to purify methane from CMM and process methane into compressed natural gas (CNG) with a heat value of 31.4 MJ/m^3 according to the national standard of "Compressed Natural Gas as Vehicle Fuel" in China. There are several technologies to purify CMM. In this option we chose PSA (pressure swing adsorption) purification technology to test the financial feasibility. The target market for CNG is for vehicle use (mainly taxis and buses) in both Qianxi County and other nearby cities.

The production equipments in this solution are divided into eight sections: gas pressurization, VPSA methane enrichment, methane-rich gas compression, deoxidation of methane-rich gas, VPSA methane concentration, natural gas compression, CNG products filling and storage, CNG filling substations; water, electricity, gas and other utilities that are required in production equipment can be supplied from Qinglong mine’s existing facilities.

The solution's production scale is mainly decided by gas volume. According to production statistics from ground high vacuum gas gathering station of Qinglong mine, under the normal production circumstances, the amount of gas extraction is: 6000Nm^3/h, the proposed gas processing plant capacity is 6000Nm^3/h.

The total investment is 44.31 million Yuan. Once the project is completed and launched, the average annual sales revenue will be 44.4 million Yuan. While the industry benchmark rate of ic = 12.0%, the financial internal rate of return (IRR) of for entire investment before tax and after-tax are 27.75% and 19.15%. The static payback period is 4.38 years and 5.42 years (including construction period of 1 year). The financial net present values (NPV) are 25.77 million Yuan and 1,100 Yuan. This indicates that the solution has a good economic benefit.

In addition, the sensitivity analysis and break-even analysis indicate that this option has good ability to resist financial risks. Operational risk analysis also showed that this option does not have uncontrollable risks, but implementation of this project will have some risk on collaboration (relating mostly to CNG transportation through tankers, setting up CNG filling station with the public transportation sector, and vehicles conversion). Based on comprehensive weighing of risks and benefits, we believe that this option looks more attractive than the power generation option does.

1.2 Comparison of end-use utilization options

According to the evaluation criteria prepared in advance, we made a comprehensive comparison of these two options on gas utilization regarding three aspects: financial benefits, social benefits, emission reduction and environmental benefits.

Comparative analysis of financial benefits: Both options have financial net present values of investment that are much greater than zero, indicating that both have the potential to make profit, but CNG’s overall economic performance is far better than power generation, such as a higher level of profitability (see financial net present value of investment, high total investment yield contrast), and a stronger ability to finance (high financial internal return rate of investment), with a shorter payback period. On the other hand, it requires a much larger amount of fixed and working capital than power generation.

<u>Comparative analysis of financial risk</u>: Through sensitivity analysis and comparative analysis, we examined these two options for financial risk resistant ability. We examined four common (and thus relatively comparable) operational parameters that will impact the internal rate of return of alternative options, to study when they change in the same range (-20% to +20%), and the difference between their effects to the continued stability of their overall economic performance. The results are listed as follows:

Table 2. Comparative analysis of financial sensitivity of alternative utilization options

Magnitude of changes	**Power generation option**		**Gas manufacturing option**	
	Variables (power generation)	After tax financial internal rate of return on investment (%)		Variables (CNG)
+20	Electricity sales price	14.13	30.90	Gas sales price
+10		11.41	25.15	
-10		5.53	12.76	
-20		2.31	5.73	
+20	Electricity sales amount	12.88	29.99	Gas sales volume
+10		10.75	24.68	
-10		6.27	13.29	
-20		3.86	6.92	
+20	Gas price	7.53	18.16	Gas price
+10		8.05	18.66	
-10		9.06	19.64	
-20		9.56	20.13	
+20	Construction investment	4.98	13.69	Construction investment
+10		6.64	16.23	
-10		10.78	22.58	
-20		13.47	26.68	

Table 3. Comparison of utilization options: risk factors and rating comparison

Power generation solution	**Gas manufacturing solution**
Market risk	
High risk (1), medium risk (1)	Low risk (2), uncertain (2)
Gas source security risks	
Low risk (2), high risk (1)	High risk (1), low risk (2)
Technical risk	
Low risk (2)	Medium risk (2)
Environmental and safety risks	
Low risk (1), unknown (1)	Low risk (3)

Financing risk	
Low risk (1)	Unknown risks (2)
Policy risk	
Medium risk (1)	Low Risk (1)
Collaborative risk	
Low risk (3)	Low risk (1), unknown risk (2)

Emission reduction benefits comparison:

- Gas power generation option: In the first project phase, there are four 500KW power generation units. With 5,500 hours annual operating time and a methane consumption rate of 0.384Nm^3/kWh, the annual power output can reach 11 million kWh. Less the power needs for self-consumption, it has 9.81 million kWh to sell to the grid. Those gas engines will reduce methane emissions of 4.224 million m^3 and supply 8,893 GJ of heat (converted to 3,826 tons of standard coal). Based on the volume of methane utilized, the power generation option will reduce 65,714 tons of CO2e annually.
- CNG from CMM option: With installed production capacity of 6000Nm^3/h CMM processing, and 1500Nm^3/h of CNG processing capacity (equivalent to standard gas), if the annual production time is 8000 hours, the annual production capacity of this project will be 12 million Nm^3 CNG (equivalent to 171,360 tons of CO2).

Social and economic benefits comparison: Whether it is gas power generation or gas manufacturing, their objectives are both aligned with the policies of energy conservation, cleaner production, and promoting safety in coal mines and comprehensive resource utilization through "promoting extraction through utilization" and " promoting mining through extraction". However, the gas manufacturing solution seems to have more potential, with significant social and economic benefits, such as: enhancing national energy security with alternative energy; extending the industrial chain to increase the value of the coal industry; and promoting local employment.

1.3 Conclusion

Qinglong mine is a stable active mine and is expected to reach its design capacity (1.2 m t/a) in 2014. Current surplus CMM after being utilized for power generation is more than 11 million m^3 and the amount will increase to 17 million m^3 in 2014. However, power generation is unlikely to consume most, not mentioning all the surplus gas due to constraints to sell electricity to the grid. Through this pre-feasibility study, we find CMM to CNG has much better financial performance compared to power generation. This option has the potential to utilize most of the surplus CMM. We recommend investors to engage with Qinglong mine and co-develop a full scale feasibility study in order to carry out this project.

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

1. For Qinglong Coal Mine, both of the above utilization options can promote coal mine safety in production, improve utilization efficiency of coal resources, protect the atmosphere, and are technically feasible with adequate gas supply security. Looking from the economic, technical and other micro level aspects of project, the two options have their respective merits and weaknesses: power generation has advantages like small investment, quick results, short payback period, and a technologically highly-skilled mine management. For the gas manufacturing option, while the initial investment is large, the cost of financing is high and the investment recovery period is long, but the long-term income prospects and the return on investment are higher than the power generation option. At the moderate and macro level, gas manufacturing's comprehensive economic and environmental emission reduction benefits are superior to power generation, as its prospect of development is much wider.

2. The biggest operational risks associated with implementation of the gas manufacturing option include negotiating settlement for outbound tankers, arrangement with the transportation company, and negotiating with urban public transport companies regarding filling station construction and vehicle modification, as well as financing risks in project construction. The biggest operational risk associated with implementation of gas power generation is to negotiate settlement with the power grid company for arrangement of grid connection.

3. Although the gas power generation option is easy to manage, because of its low energy conversion efficiency, it is not the best way to use gas resources. Gas manufacturing is a kind of technology innovation for Qinglong mine, and it has broad market prospect; but because of its technology involvement and complex transaction processes, its learning costs, expected management, and transaction costs are higher than power generation.

4. The primary purpose of gas extraction and utilization is to promote safety in coal mine production. Because the natural gas market is enormous in Guizhou where oil and gas reserves are limited and there is difficulty in grid connection for gas power generation, and coal mine's own demand for electricity is limited, we have reason to believe that gas manufacturing has more potential than gas power generation.

5. For Qinglong mine, the gas utilization option proposed by two design institutes may be complementary rather than mutually exclusive. This is because the gas concentration applicable to power generation and gas purification do not over-

lap: the gas purification scheme uses gas with concentrations mainly of above 25% extracted through high-vacuum drainage, then the low concentration gas can be used for power generation; while the power generation solution's coverage of concentration requirement seems to be bigger, where high vacuum and low vacuum drainage of gas can be mixed for use. Thus, if funding available is abundant, power generation and gas manufacturing can be considered in parallel to optimize allocation for different concentrations of gas resources in two ways of utilization. One of the potential advantages of an optimized parallel solution is that the gas power generation plant can supply electricity to the gas manufacturing plant, to partially alleviate the pressure on gird connection. The potential risk will be increased cost in internal coordination (coordinating the demand and relationship between gas power plant and gas manufacturing plant).

6. Compared with gasoline, diesel and LPG vehicles, CNG vehicles have irreplaceable advantages in terms of environmental protection, economy and safety and are more feasible in terms of technology maturity than LNG vehicles. However, LNG's advantage in storage is obvious, gas filling is faster than CNG vehicles, and is likely to compete with the gas manufacturing CNG option. Combined with the natural gas utilization plan of Guizhou ("Send gas from Sichuan into Guizhou," "Send gas from Myanmar into Guizhou"), the possible trend for development of a natural gas vehicle industry in Guizhou could be as follows: In the early development stage, use CNG-gasoline dual-fuel natural gas vehicle conversion technology to launch the car market, and gradually build a filling station system, and the modified models would be mostly gasoline-powered bus and taxi. In the middle development stage, the focus will be direct introduction of CNG-only natural gas vehicle. In the long term, with the introduction of LNG gas supply and maturity of LNG technology, the process would achieve common development of CNG vehicles and LNG vehicles. For Qinglong Coal Mine, development of a CNG manufacturing project in Guizhou requires attention and focus on the mid and long term trend of "oil to gas conversion" market in the transportation system, in order to position in favorable standing in the increasingly competitive automotive fuel market.

2.0 Project Overview

2.1 Background of pre-feasibility study

This report is compiled by the experts in charge of Guizhou Provincial Environmental Protection International Cooperation Center, a subsidiary of Guizhou Provincial Environmental Protection Bureau, to support the Global Methane Initiative (formerly the Methane to Markets Partnership). The program aims to use market-oriented measures to promote reduction of methane emissions, an important greenhouse gas, and fully exploit it as a clean energy. As a founding member country of GMI, China recently introduced many policies to actively promote CMM (composed mainly of methane) utilization. The main objective of the project is to compile a pre-feasibility study report of CMM utilization for two coal mines in Guizhou, in order to promote full use of CMM resources and to reduce methane emissions; Qinglong mine is one of the two mines selected to carry out pre-feasibility study of the project. The implementation of the project research is funded by the U.S. Environmental Protection Agency.

2.2 The proposed project location and general description

Gu Li town, where Qinglong mine is located, is in the eastern part of Qianxi country, Bijie Region, the northwestern Guizhou Province. The coalfield's geographic coordinates are: longitude 106 ° 03'26 "~ 106 ° 10'32", latitude 26 ° 57'51 "~ 26 ° 59'32" (see below).

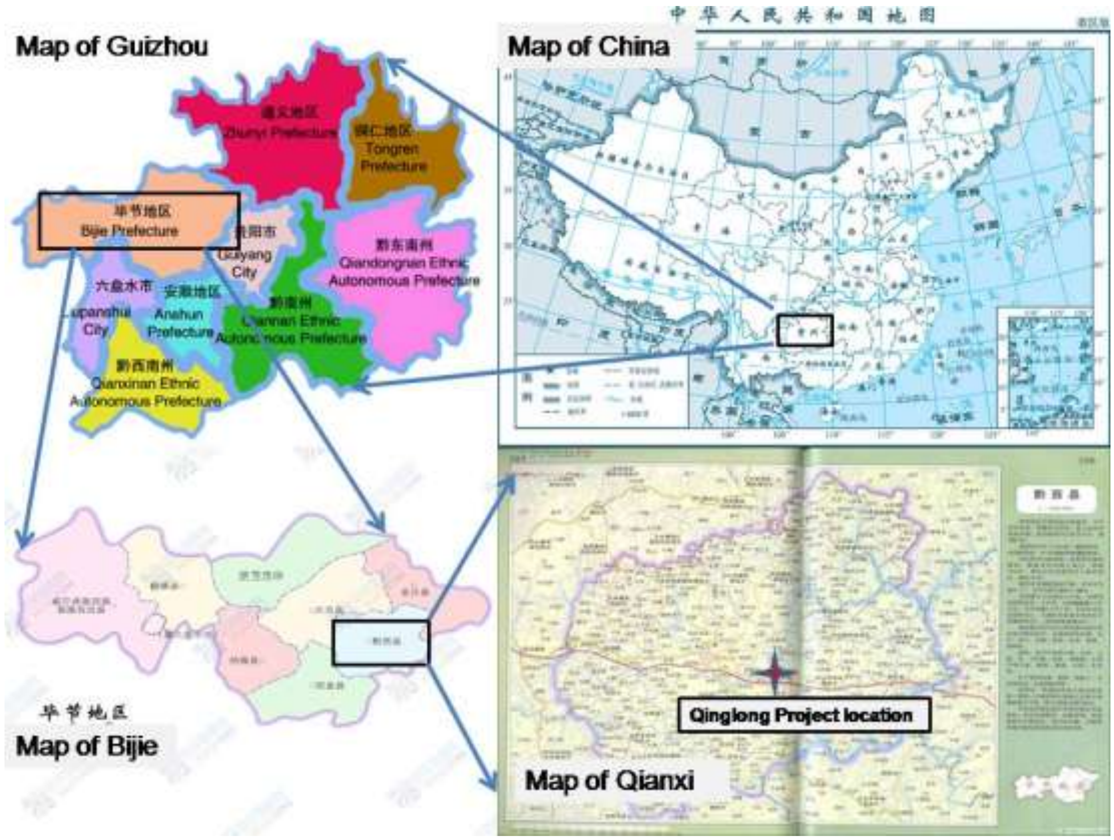

Figure 1. Qinglong mine's geographical location

The transportation is convenient in this minefield: it is 68km away from the Zhazuo station of Sichuan-Guizhou railway to the east, and 90km away from Yantangkan station of Guiyang-Kunming line extension to the north. Guibi high grade road passes through the middle of coalfield; by using Guibi high grade road, the minefield is 14km away from Qianxi County, 104km away from Guiyang, 105km away from Bijie. In addition, the backbone of Qianxi - Supu highway also passes through the middle of the minefield. For Tuomei River to the northwest of the minefield, although it is not suitable for navigation, it can provide ample water for the project.

Qinglong Minefield is about 9.0km from north to south, and is 1.6 ~ 5.0km wide from west to east, with area of 26.5 km2. The geological reserve of coal is 190.21 million tons, with recoverable reserve of 89,069 million tons. Its designed production capacity is 1.2 million tons/year. This mine is a high-gas coal mine; the gas resources are very abundant with reserve of about 2.85 billion m^3, extractable gas of about 1.34 billion m^3. In 2005, the coal mine had gas extraction of 4.46 million m^3, and extraction amount had increased year by year. By 2010, the annual extraction reached 16 million m^3. The amount of extraction is expected to reach 20 million m^3 in 2011.

With the increasing amount of surplus gas, the project studied two gas utilization options:

1. Power generation;

2. Manufacturing CNG through gas preparation and purification.

2.3 Project sponsor’s background and financial status

2.3.1 Yanzhou Mining Guizhou Energy and Chemical Industry Co., Ltd

Qinglong Coal Mine is the first large-scale modern mine that is held, developed and constructed in Guizhou by Shandong Yanzhou Mining Group, specifically, developed and constructed by Guizhou Qianxi Energy Development Co., Ltd., a subsidiary of Yanzhou Mining Guizhou Energy and Chemical Industry Co., Ltd (referred to as "Yanzhou Guihua" in the following). Yanzhou Mining Group, the parent company of Yanzhou Mining Guizhou Energy and Chemical Industry Co., Ltd, is a pilot company of China’s 100 modern enterprise system and 120 enterprise companies, and is also the first company in China's coal industry to go public to list simultaneously in New York, Hong Kong and Shanghai stock market. The company's total assets are about 25.2 billion and currently have 50 wholly owned subsidiaries, holding companies and joint venture companies. The company has world-class comprehensive caving techniques and is ranked top 10 companies for national promotion by the State Department regarding state-owned enterprises reform and development. Yanzhou Mining Group is trying to build China's largest coal production and export base, world-class clean coal and new generation of coal chemical production base.

Yanzhou Mining Guihua is a subsidiary established by Yanzhou Mining Group in 2002 in Guizhou after it involved in the project of "Abundant coal guarantee abundant power", and is absolutely controlled by the Yanzhou Mining Group. As Yanzhou Mining Group's investment platform in Guizhou Province, Yanzhou Mining Guihua was established according to modern enterprise system, with independent legal person status.

In July 2010, Yanzhou Mining Group introduced China's Coal Mines (Overseas) Group Co., Ltd., becoming the strategic investors of Yanzhou Mining Guihua Co., Ltd. Headquartered in Hong Kong, the China Coal Mines (Overseas) Group has a background of profound international capital, with extensive experience and strong strength in capital operation and resource integration. Its major shareholders and strategic partners include CCB International Asset Management Company, China Everbright Holdings Company, Merrill Lynch and other well-known multinational companies and international consortia. The group injected capital of RMB 2.026 billion Yuan to Yankuang Guizhou Energy and Chemical Industry Co., Ltd; the injected capital account for 46% of the registered capital thereafter (Yanzhou Mining Group remains a controlling stake of 54%). The capital increase is mainly used for Yankuang Guizhou Energy and Chemical Industry Co., Ltd’s holding of coal mines under construction and proposed, acquisition, integration and reorganizing surrounding medium- and small-sized coal mines, coal washing and dressing, CMM comprehensive development and utilization, coal mine integrated technology development of safety information and management resources, and equity investment in power plant projects and other capital investment.

In the "Twelfth Five-year program" period, Yankuang Guizhou Energy and Chemical Industry Co., Ltd plans to form the framework for five major sectors, including coal mining, washing and processing, mechanical and electrical equipment manufacturing, gas utilization, and modern logistics trade. By the end of the "Twelfth Five-year program", the annual coal production capacity within the region will reach 15 million tons in Guizhou region, the installed capacity of coal and CMM power generation will reach 1 million kilowatts, with annual sales income of over a ten billion Yuan. In respect to CMM utilization, Yankuang Guizhou Energy and Chemical Industry Co., Ltd has actively contacted related companies, including Hong Kong Towngas in Hong Kong.

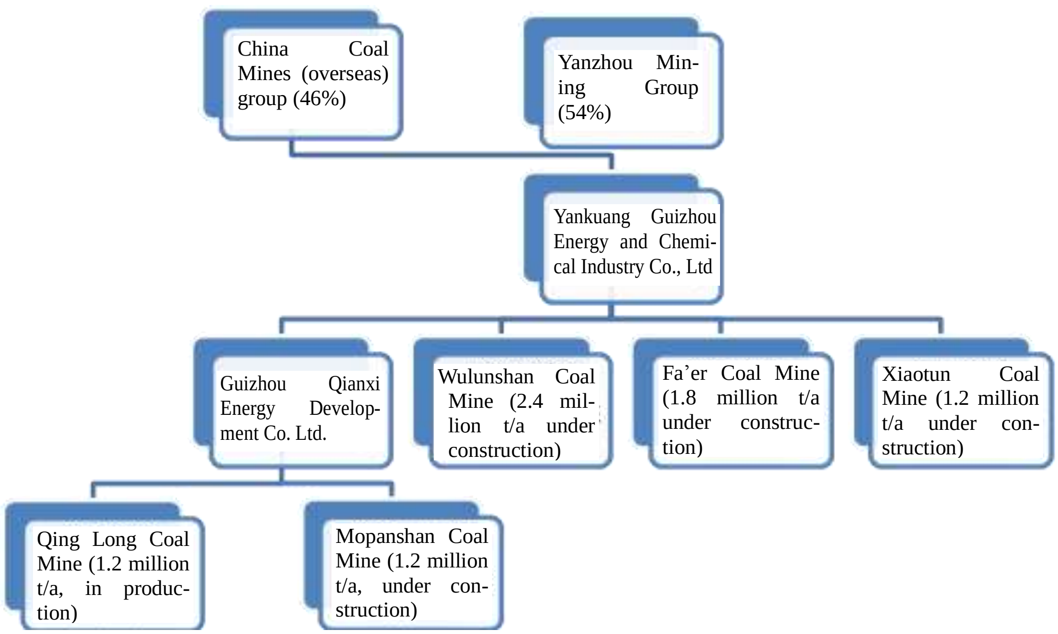

Figure 2. Holding structure and subordinate coal mines of Guizhou Energy and Chemical Industry Co., Ltd

2.3.2 Guizhou Qianxi Energy Development Co., Ltd.

Qinglong Coal Mine was developed and constructed directly by the Guizhou Qianxi Energy Development Co., Ltd. The corporation was jointly established in January 2004 by Yankuang Guizhou Energy and Chemical Industry Co., Ltd, Guizhou Zhongshui Energy Development Co., Ltd., Guizhou Qinglong Industrial Co., Ltd. and Guizhou Qianxi County Qianfa Coal and Electricity Investment Company, the ratios of investment are 47%, 30%, 18%, and 5%. Qinglong Mine is one of the two "garden-like" large-scale coal mines developed by Guizhou Qianxi Energy Development Co., Ltd. in

Qianxi County (the other is Mopanshan mine[1]).

3.0 Qinglong Coal Mine's exploration of coal and CMM resources

3.1 Coalmine's geological environment

3.1.1 Terrain features

Qinglong minefield has a terrain that is generally subject to regional geological structure and lithology and belongs to highland hilly terrain. The landform in minefield is simple, with relatively flat terrain, the general elevation is 1250 ~ 1350m above sea level, relative height is generally 100 ~ 150m. The elevation of highest point is 1474.2m (Yingpanshan), and the elevation of lowest point is 1155m (Huadi, Tuomeihe), with maximum relative height of 319.2m. The general trend of the terrain within the minefield presents a pattern with high level of Southeast, and low level of Northwest.

3.1.2 Geological structure

The tectonic structure of the minefield area is located at Yangzi paraplatform, Qianbei platform uprise, Zunyi fault arch, and Bijie NE deformation zone. Today's outline of structure was formed by crustal movement in Yanshan period. The structural trace features mostly folds and faults to the NE, and a small amount of faults from near EW and NW to SE. The region's folds are mostly broad asymmetrical anticline and syncline. For exposed strata in the area, in addition to basic extrusive rock (basalt) at Gelaozhai anticline core of the minefield boundary, the rest are all sedimentary rocks.

From old to new order, the distribution of geological formations is: Lower Permian system Maokou formation (P1m) limestone; upper Permian system Emeishan basalt (P1β), Longtan formation (P2l) coal-bearing clastic rocks, Changxing formation (P2c) limestone; Lower Triassic system Yelang formation (T1y) limestone and clastic rocks, Maocaopu formation (T1m) limestone and dolomite; middle Triassic system Songzikan formation (T2s) clastic rocks and limestone, Shizishan formation (T2sh) dolomite and dolomitic limestone. Among them, coal-bearing strata are concentrated in Longtan formation.

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[1] Mopanshan coal mine is associated with Qianxi power plant that is located in Mopanshan, Fangjiatian Village, Tailai Township of Qianxi County, with overall designed production capacity of 2.4 million tons/year, and 1.2 million tons/year in the first phase. The mine started exploration in 2006, and passed the review by expert panel of key project pre-feasibility study report of Guizhou Coal Resource Construction in April 2006. It was originally planned to start construction at the end of 2008, but due to the mining right allocation solution has yet approved by the Department of Land and Resources in the province, and the decision of the Ministry of Land and Resources was pending, it was postponed to December 2009 to start construction.

3.1.3 Fold and fault

Qinglong minefield is located in the North West Wing of Gelaozhai anticline. The anticline is an asymmetric broad, gentle anticline. The anticline core is located near the southern end of minefield, and is composed of lower Permian system Maokou formation (P1m) and basalt (P1β), and gradually extend toward minefield's north-west boundary into upper Permian system Longtan Formation (P2l), lower Triassic system Yelang formation (T1y). Its axis is located in the south east of the minefield, and is the boundary of minefield. The anticline axial direction is 217 ~ 37°, and the axis features slight wavy distortions and pitches to both ends, extending in the minefield about 7km.

The formation in North West Wing fold is basically monoclinic output, but under the influence of the regional structure, secondary smooth wave deflections often occur in monoclinic structure, in which from section A10 to section A3, from east to west, gradually develop into a clear protruding structural nose toward west, with axis length of about 3km. The dip direction of strata is mostly NW, while in the NE of minefield, the anticline's pitch sections convert to NE dip direction, and the formations to the south of the structural nose axis general dip to SW. The formation dip angle is between 4 ~ 28 °, and normally 9 ~ 16 °. At southern tip of the minefield, due to the impact of fault F3, the local dip angles can be above 60°, and the dip directions also change. The SE wing of anticline dips to SE, with dip angles of up to 45 at faults.

There are three regional fault structural distribution in NW and SW of minefield, which are F1, F2, F3. They constitute a natural boundary at NW and SW of minefield. There are limited number of faults within the minefield, and only three large secondary faults include F4, F5, F6 are found. Among them, F5 is located at the North Eastern edge of this minefield, therefore basically has no influence to the coalfield.

3.2 Coal and CMM resources and reserves

3.2.1 Coal endowment

Within the range of Qinglong Coal Mine's coalfield, there are total 15 coal-bearing strata, in which there are 6 recoverable or locally recoverable coal layers, which are M2, M3, M9, M16, M17 and M18 from top to bottom respectively. Among them, M16, M18 are the major recoverable coal layers, M17 is partially recoverable coal layer, M2, M3, M9 and others are locally recoverable coal layers. The coal-bearing strata's average coal seam thickness is 11.02m, with coal bearing ratio of 4.6%. In the main coal-bearing strata, the total coal seam thickness is between 2.44 ~ 22.26m, with average thickness of 8.90m, and coal bearing ratio of 10.1%. According to what drilling project had revealed, the total thickness of recoverable coal seams is between 2.08 ~ 20.29m, with average coal seam thickness of 7.67m. The major characteristics of coal seams are as below.

Table 4. Qinglong minefield's major coal seam features

<table>
<tr><th rowspan="2">Coal Seam Name</th><th colspan="6">Coal seam</th><th rowspan="2">Stone band Layers</th></tr>
<tr><th>Range of recoverable thickness (M)
Two extreme value
Mean value</th><th>Variation ratio (%)</th><th>Structure</th><th>Stability</th><th>Recoverability</th><th>Seam Spacing (M)
Two extreme value
Mean value</th></tr>
<tr><td>M16</td><td>0.81~9.64
3.55</td><td>85</td><td>Pretty Simple</td><td>Stable</td><td>Recoverable for the whole area</td><td rowspan="3">3.10~22.80
12.58
2.80~21.60
10.49</td><td>0 1</td></tr>
<tr><td>M17</td><td>0.80~2.38
1.34</td><td>76</td><td>Simple</td><td>Pretty stable</td><td>Partially recoverable</td><td>0</td></tr>
<tr><td>M18</td><td>0.95~8.27
3.05</td><td>68</td><td>Pretty Simple</td><td>Stable</td><td>Mostly recoverable</td><td>1 2</td></tr>
</table>

3.2.2 CMM occurrence

Qinglong Coal Mine's gas resources are relatively rich, with gas reserves of about 2.85 billion m^3, in which exploitable gas of about 1.34 billion m^3; the gas reserves and extractable gas amount for the coal seams (including non-recoverable seams and surrounding rock) are listed in the table below. With the continuous improvement to the drainage system and borehole techniques, the drainage efficiency will gradually increase and the amount of extractable gas will continue to increase. This will provide adequate resources conditions for CMM development and utilization.

Table 5. Qinglong mine gas reserves and exploitable volume

<table>
<tr><th>Coal seam</th><th>Gas Content (m^3/ton)</th><th>Coal Geology Reserves (million ton)</th><th>Gas reserves (Millionm^3)</th><th>Extract Ratio</th><th>Exploitable gas volume</th></tr>
<tr><td>16</td><td>11.87</td><td>10799</td><td>128,184.1</td><td>0.497</td><td>63695.1</td></tr>
<tr><td>17</td><td>13.18</td><td>994</td><td>13100.9</td><td>0.335</td><td>74387.1</td></tr>
<tr><td>18</td><td>13.05</td><td>7228</td><td>94325.4</td><td>0.453</td><td>42694.9</td></tr>
<tr><td colspan="3">Non-recoverable coal seam and surrounding rock</td><td>49478.2</td><td></td><td>23263.2</td></tr>
<tr><td colspan="2">Total</td><td>19021</td><td>285,088.6</td><td></td><td>134,040.2</td></tr>
</table>

3.2.3 Gas source analysis

3.2.3.1 Gas content analysis

The coal seams in Qinglong Mine are of high gas and high metamorphic coal, presenting a trend that CMM content increase gradually with the depth of seam. According to a geological report of gas composition test and analysis toward the coal core within the minefield, the gas content of recoverable coal seams is generally high. The gas content changes for the major coal seams of M16, M18 and partially recoverable coal seam of M17 are summarized as below:

M16 coal seam: Gas content is between 10.46 (ZK402) ~ 17.02 (ZK1302) m^3/t flammable; the major gas component is methane. The resulted methane content of non-air based component when gas was tested after degassing under room temperature is between 64.78 (ZK1301) ~ 99.54% (ZK403), with average content of 87.76%.

M18 coal seam: Gas content is between 5.23 (ZK601) ~ 20.54 (ZK102) m^3/t flammable; the resulted methane content of non-air based component when gas was tested after degassing under room temperature is between 16.22 ~ 98.92% (ZK601), with average content of 87.59%.

M17 coal: Gas content is between 12.13 (ZK402) ~ 13.19 (ZK503) m^3/t flammable; the resulted methane content of non-air based component when gas was tested after degassing under room temperature is between 34.05 ~ 99.43%, with average content of 84.96%.

By converting into raw coal content, we obtained gas content values of the major coal seam drillings from the initial mining areas which are shown in the following table:

Table 6. Statistics of gas content value of drilling in initial mining area

Drilling No.	**M16 coal seam**		**M18 coal seam**	
	Elevation	Gas content (m^3/t)	Elevation	Gas content (m^3/t)
Zk101			1070.51	8.93
Zk102			896.15	17.39
Zk103	1018.19	9.99	1055.55	14.03
Zk301			1177.95	10.47
Zk302	1165.67	12.48	1117.29	10.20
Zk303	1192.62	13.06	1157.03	15.42
Zk401	1253.15	10.06	1219.32	14.49
Zk402	1225.21	9.01		
Zk403	1195.36	12.84	1166.55	14.90
Zk503	1197.18	10.88	1170.31	11.83
Zk601			1211.87	4.43

Zk602	1166.86	10.92	1138.70	7.69
Zk603			1150.25	10.89

3.2.3.2 Gas emission volume analysis

The three major sources of coal mine gas emission include mining, tunneling, and gathering. While gas emissions come mainly from the coal seam, surrounding rock and adjacent coal seams and shed coal. Gas emissions are calculated according to coal seam's gas content, coal seam thickness, mining height, face yield and other parameters, considering emissions from coal wasted at mining field, gas zone pre-drainage in roadway and excavation, surrounding rock and adjacent coal seams, and shed coal, etc. The expected results for M16's gas emission at coal seam's mining face are as follows:

Table 7. Summary of gas emission at workface of mining areas

Face Number	**Gas emission (m^3/t)**	**Face Number**	**Gas emission (m^3/t)**
1601 mechanized mining face	21.41	1602 mechanized mining face	12.86
1603 mechanized mining face	North 15.31, South 24.47	1604 mechanized mining face	15.01
1605 mechanized mining face	15.31	1606 mechanized mining face	16.01
1607 mechanized mining face	Northern 13.71, South 21.26	1608 mechanized mining face	18.31
1609 mechanized mining face	Northern 12.11, South 14.98		
1611 mechanized mining face	10.51		
1613 mechanized mining face	8.91		

Gas emission during tunneling can be divided into two categories, coal dropped in heading face and roadway coal wall, and is calculated according mainly to coal seam gas content, driving speed, seam thickness, tunneling section and other factors. The expected results of gas emission from M16 coal seam's heading face are as follows:

Table 8. Summary of the gas emission from mechanized excavation face of the first mining area

Face Number		**Gas emission (m^3/min)**	**Face Number**		**Gas emission (m^3/min)**
1601 mechanized excavating face	Transportation roadway	3.85	1602 mechanized excavating face	Transportation roadway	3.71
	Roadway trough	3.73		Roadway trough	3.60
1603 mechanized excavating face	Transportation roadway	4.13	1604 mechanized excavating face	Transportation roadway	3.70
	Roadway trough	4.00		Roadway trough	3.58
1605 mechanized excavating face	Transportation roadway	2.94	1606 mechanized mining face	Transportation roadway	3.82
	Roadway trough	2.86		Roadway trough	3.70
1607 mechanized excavating face	Transportation roadway	2.96 ~ 4.44	1608 mechanized mining face	Transportation roadway	4.13
	Roadway trough	2.88 ~ 4.29		Roadway trough	4.00
1609 mechanized excavating face	Transportation roadway	3.16 ~ 4.55			
	Roadway trough	3.07 ~ 4.40			

1611 mechanized excavating face	Transportation roadway	3.35～4.46			
	Roadway trough	3.25～4.31			
1613 mechanized excavating face	Transportation roadway	3.74			
	Roadway trough	3.63			

In addition to emission from excavating face and mining face, the gas emission from gob includes emission from goaf and other areas. According to Qinglong mine's coal seam occurrence conditions, it is initially calculated by 20% of excavating and mining face emission, and then by 30% of total excavating and mining face emission.

The amount of gas emission varies with the intensity of coalbed exploration, relationship between equipment and mining, and mining sequence. Based on succeed sequence and workface connection relationship in exploring and mining design, the expected gas emission results in different mining periods are as follows:

Table 9. Expected gas emission when coal mine achieves design capacity

Allocated production face		Daily yield (t)	Gas emission	
			Relative volume (m^3/t)	Absolute volume (m^3/min)
A	Gas emission in coal mining			
1	M16 coal seam mechanized mining face	3667	12.86	32.75
2	Coal mining total	3667	12.86	32.75
B	Gas emission in excavating			
1	M16 coal mechanized excavating face (roadway trough)	187		2.86
2	M16 coal mechanized excavating face (roadway belt)	218		2.94
3	Tunneling total	405		5.80
C	Gas emission proportion in Gob			0.20
D	Whole mine total	4072	16.36	46.26

Table 10. Expected gas emission of coal mine in late period

Allocated production face		Daily yield (t)	Gas emission	
			Relative volume (m^3/t)	Absolute volume (m^3/min)
A	Gas emission in coal mining			
1	M16 coal seam mechanized mining face	3667	21.26	54.14
2	M18 coal seam mechanized mining face	4000	8.92	24.77
3	Coal mining total	7667	14.82	78.92
B	Gas emission in excavating			
1	M16 coal mechanized excavating face (roadway trough)	162		3.58
2	M16 coal mechanized excavating face (roadway belt)	187		3.70
3	M18 coal mechanized excavating face (roadway trough)	161		2.35
4	M18 coal mechanized excavating face (roadway belt)	185		2.44
	Tunneling total	695		12.07
C	Gas emission proportion in Gob			0.30
D	Whole mine total	8362	22.41	130.11

It can be seen from the expected results, the relative gas emission when the mine achieves design capacity will be 16.36 m^3/t, and the absolute emission will be 46.62 m^3/min. According to actual extraction data, the current absolute emissions are about 30-35 m^3/min, which is close to the theoretical prediction. Given this mine has not achieved its designed capacity (production close to 1 million tons in 2010), the current extraction volume will see further increase. In Table 9, it shows anticipated gas emission when this mine achieves 2.4 million tons of annual production. It is still unknown when the mine can achieve this production capacity, so this report does not include this part of potential of gas resources and utilization means.

3.2.4 Gas extraction and utilization status quo

3.2.4.1 Extraction status quo

As a state-owned medium or large scale coal mine, the Qinglong had started a mine ventilation system, gas extraction system, and gas monitoring system since it launched a pilot operation at the end of 2004. The design principle of the mine is that 45% of gas emission will be exhausted through ventilation system, and the remaining 55% will be collected through the gas drainage system.

According to this principle, the gas drainage station of the mine has two permanent ground drainage systems installed, with a total of four drainage pumps. One of the systems is of high vacuum, and equipped with two 220 kilowatts high vacuum SKA420 drainage pump, with gas drainage capacity of 9 cubic meters per minute. The other system is of low vacuum, using two 280 kilowatts SKA500 water-ring gas drainage pumps, with one in use, the other in backup, with gas drainage capacity of 10 cubic meters per minute. In addition, Qinglong mine had installed gas drainage pipe of total 13,600 m, and drilled drainage holes of 252,700 m. For underground high concentration gas drainage system, it used iron pipes of 560 mm diameter as the main drainage pipeline of the mine, and used PE pipes of 200 to 315 mm diameter as trunk pipe. For low concentration gas drainage system, it used iron pipes of 720 mm diameter as the main drainage pipeline of the mine, and used PE pipes or iron pipes of 300 to 400 mm diameter as trunk pipe, to ensure the flow of CMM drainage.

For high vacuum gas drainage system, the concentration of gas drainage is kept in the range of 24 to 30% for long term; the net flow of gas drainage is between 18 ~ 20m^3/min (100% pure gas). For low vacuum gas drainage system, the concentration of gas drainage is kept in the range of 8 to 10% for long term; the net flow of gas drainage is between 12 ~ 15m^3/min (100% pure gas). According to "Gas drainage and ventilation data collection forms" provided by Qinglong Mine, from January 2008 to December 2009, in the two years, the concentration of gas was between 20% and 27%, which is very stable. In 2010, the gas concentration for high vacuum drainage has stabilized at 25% basically, with flow range of 15 ~ 20 m3/min; the gas concentration for low vacuum drainage is in the range of 8% to 11%, with flow range of 10 ~ 14 m^3/min. The high vacuum pump is now running at full capacity, and they are planning to add a SKA670 drainage pump in 2011, that will ensure that annual drainage to reach 20 million m^3 at the drainage pumping stations.

The composition of Qinglong mine's gas is listed in the table below, and the data come from the average of eight samples in 2010 and 2009.

Table 11. Table: Analysis of the composition of Qinglong mine's gas

Gas-taking location	Gas composition %							Others
	Methane	Carbon dioxide	Carbon monoxide	Oxygen	Ethylene	Ethane	Acetylene	
High	23.28	0.13	0.00	13.68	0.00	0.01	0.00	62.91

vacuum								
Low vacuum	9.31	1.52	0.00	15.85	0.00	0.00	0.00	73.31

3.2.4.2 Methane utilization status quo

The current use pattern for gas is power generation. There is currently a gas power plant with installed capacity of 3400KW. The units include 4 units of 500KW (low concentrations units), 2 units of 700KW (high concentration units). In 2009, the gas extraction volume is 11,275,000 m^3, with 3,427,188 m^3 used for power generation and 7,847,900 m^3 still remained. In 2010, the total volume of gas extraction increased to 16.22 million m^3, and the gas volume used for power generation is only about 5.11 million m^3, with more than 11 million m^3 still not used. High concentration CMM power generation requires high quality feed gas for stable operation. Low concentration power generation technology can operate with low quality gas. For this reason, Qinglong mine's management even consider modifying high concentration gas units to accommodate low concentration gas.

The coal mine’s gas drainage capacity, utilization amount and power generation statistics are listed as below.

Table 12. Statistics of Qinglong Mine’s annual drilling footage, gas drainage, and gas utilization in power generation

Year	Coal mining output (t)	Drill site number	Drill hole number	Footage (m)	Drainage (ten thousand m^3)			Power generation (ten thousand kWh)	Gas utilization (ten thousand m^3)
					High vacuum	Low vacuum	Total		
2004	2542			40000			16		
2005	251656						446		
2006	140876		872	58050			437	444	171
2007	553066	288	1960	105145	471	177	647	504	194
2008	807800	254	2827	158644	509	256	765	882	337
2009	805318	149	3101	183498	575	552	1128	876	343
2010	1041425	186	4208	238236	966	656	1622	1362	511
2011	950000	200	5500	250000	1200	800	2000	1300	550
2012	1000000	220	5700	260000	1400	800	2200	1500	660
2013	1100000	250	6000	280000	1400	900	2300	1700	690
2014	1200000	260	6500	320000	1600	900	2500	1700	750
1025	1200000	280	7000	350000	1600	900	2600	1700	750

Note: the data for 2011-2015 is expected number.

As it is shown in the above table, after deducting the gas used for power generation, the coal mine has more than 10 million cubic meters of gas each year that may be used. The coal mine owners are considering adding two power generation units. Even so, in the next few years, there will still be a large amount of surplus gas to be discharged. In this regard, coal mine owners don't have specific plans to utilize this gas, but will welcome other businesses and coal mines to invest in development and utilization of coal gas.

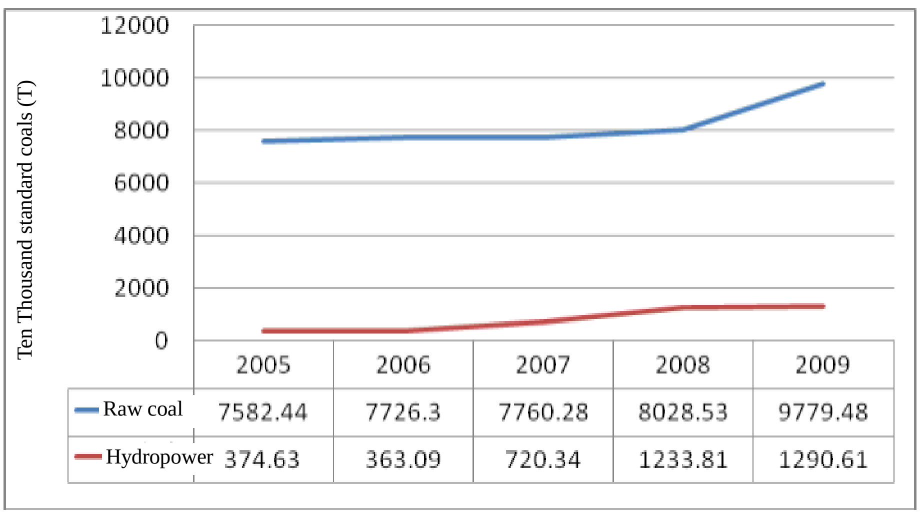
4.0 Energy production and consumption in Guizhou

This section briefly introduced the energy production and consumption in Guizhou, with focus on Guizhou's coal, natural gas, and electricity market, in an attempt to provide a background to discuss the use of coal gas. For details of this section, please refer to overall project report.

4.1 Energy production

Coal is the most important energy sources in Guizhou, in the period from 2005 to 2009; its proportion in energy production has been above 85% (see Figure 3 and Figure 4).

Figure 3. Energy production constitutions of Guizhou Province (2005 – 2009)



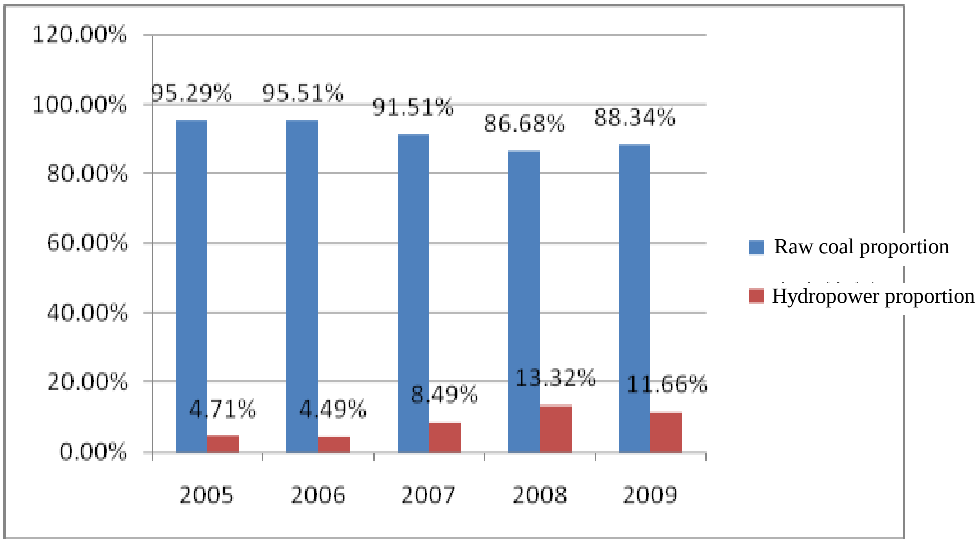


Figure 4. Energy production constitutions proportion diagram of Guizhou Province,

4.2 Energy consumption

According to the "China Statistical Yearbook 2009", coal accounts for 68.7% of total energy consumption in China, and the coal-dominated energy consumption structure is difficult to see change. For big coal producer like Guizhou province, this feature is particularly evident. According to the "Guizhou Statistical Yearbook 2010", during the period from 2005 to 2009, the province's coal consumption accounted for over 55% of total energy end consumption (see Figure 5 and 6).

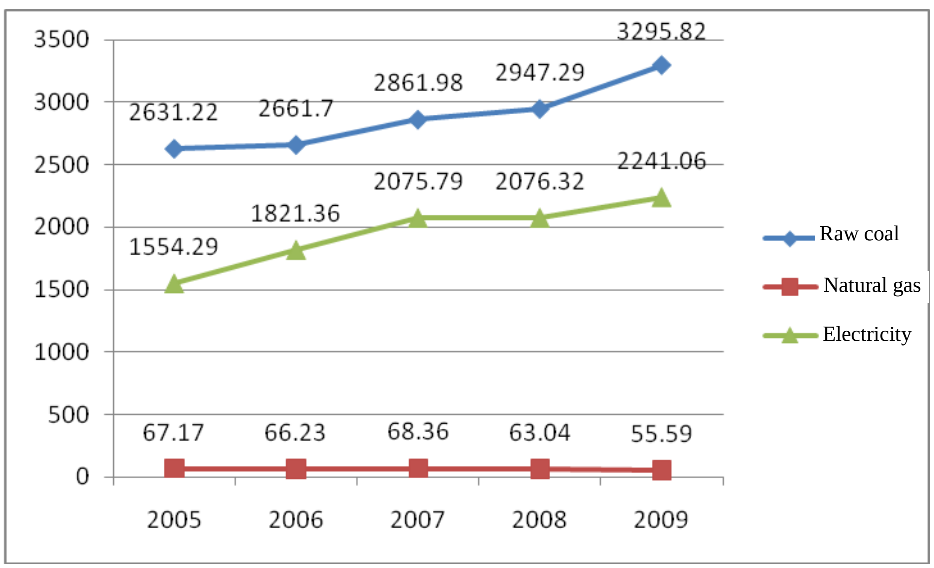


Figure 5. Energy end consumption structure chart for Guizhou Province

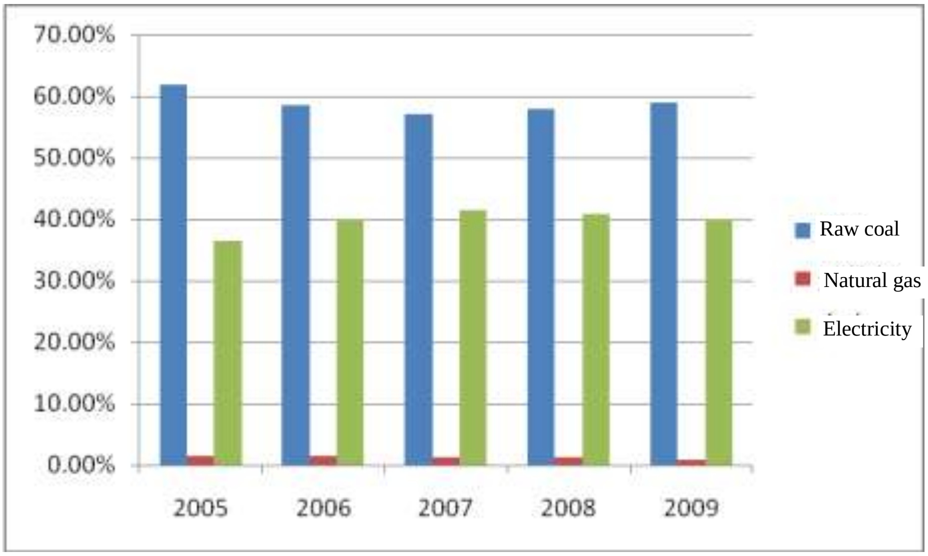


Figure 6. Proportion diagram of energy end consumption structure for Guizhou Province

As can be seen from the above diagram, coal is the main energy for Guizhou Province, and this coal-dominated energy structure will not change over a long period of time in the future, and the demand for coal will continue to grow

4.3 Guizhou's coal market overview

4.3.1 Coal consumption and demand forecast for Guizhou Province

According to data provided in Guizhou Statistical Yearbook, 2009, the province's total coal consumption is 13.1 million tons, of which the largest share being the power industry, amounts to 35.5%. The proportion of coal consumption for each industry can be seen in Figure 6. According to development plans for the industries, the energy consumption for the industries during the "Twelfth Five-Year Program" period is shown in Table 3.

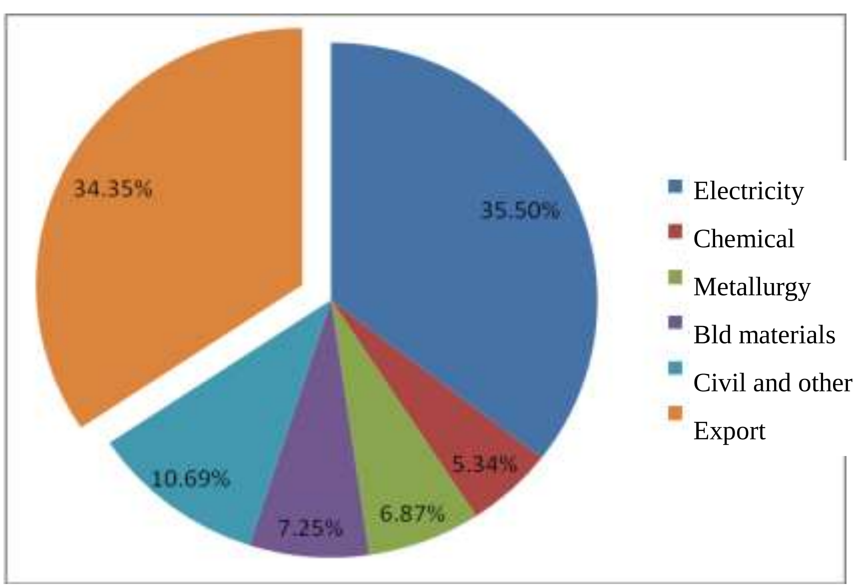


Figure 7. Energy Consumption Proportion Diagram for industries in Guizhou Province in 2009[2]

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

Coal consumption	"Eleventh Five-Year program"	"Twelfth Five-Year Program" (Planning)					Outlook
	2010	2011	2012	2013	2014	2015	2020
1. Electricity 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. Construction materials industry	1000	1000	1050	1050	1100	1100	1100
5. Civil and other	1500	1380	1360	1300	1200	1100	1100
Total demand for the province	9980	10730	11950	13190	15030	17240	21530
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 export calculated by coke products export

We can draw the following conclusions based on the above chart analysis:

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

(2) The forecast of coal demand has taken into account energy saving factor that will be brought about by technological progress, but has left with some room for the unexpected factors; if energy saving reach the predicted effect, the demand will de-

[2] 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".

crease.

4.3.2 Analysis of Guizhou coal supply and demand balance

The production capacity of existing mines in Guizhou Province and yield forecasts are shown in Table 4; the coal supply and demand balance is shown in Table 5. As can be seen from Table 4, during and in the end of the Eleventh Five-Year program, the mines with annual output of less than 300,000 tons of coal are the mainstream coal mines, the major coal producers; through the adjustment of twelfth Five-Year program to 2015, the mines with annual output of more than 300,000 tons will become mainstream coal mines; and the capacity of mines with annual output of less than 300,000 tons will be greatly reduced. As can be seen from Table 5, in accordance with output arrangement for existing registered mines and mines under construction till the end of 2009, the supply and demand in 2009 are basically balanced, the supply-demand balance difference at the end of the "Twelfth Five-Year Program" (2015) will be 30.07 million tons; the supply-demand balance difference at the end of the "Thirteen Five-Year Program" (2020) will be 86.77 million tons. 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 arrangements (million t)			
				2009	2010	2015	2020
Existing coal mines		1738	29347	13691	15363	18233	16853
In 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 tons)		13100	13480	21240	25530
Supply of coal (ten thousand	Existing coal mines	13691	14875	9405	7395
	Mines under construction (as of 2009)		488	8828	9458

tons)	Total	13691	15363	18233	16853
Supply-demand balance difference (ten thousand tons)		+591	+1883	-3007	-8677

4.3.3 Qinglong mine area coal market

Qinglong coal mine supply mainly to Qianxi Power Plant of Qianxi County, a place 19 km from the coal mine, with installed capacity of 1.2 million kilowatts (4 x 300 MW), completed by the end of 2006, with annual coal consumption of 3 million tons. The plant is currently ready to add two 660,000 kilowatts supercritical units; and the project has already started its preliminary work now.

In addition to Qianxi power plants nearby, the sales market of Qinglong coal mine includes Dafang power plant in Dafang County that is about 70 km away from the mine. Dafang power plant's first phase has a generating capacity of 1.2 million kilowatts (4 x 300 MW), and is a large thermal power enterprise invested by three investors including China Huadian Corporation, Guizhou Zhongshui Energy Development Co., Ltd. and Shandong Yanzhou Mining Group (Guizhou Energy and Chemical Industry Co., Ltd), whose contributions are respectively 45%, 30% and 25%. The plant started construction on August 13, 2003 and was put into operation in November 2007, with annual consumption of anthracite coal of 300 million tons. In December 2010, the feasibility study report of Dafang Power Plant's second phase 2 X 660MW supercritical coal-fired unit expansion project passed review and is expected to put into operation in 2014.

From the point of view in demands from local power plants, there is no problem for Qinglong Coal Mine regarding sales market; and price will be the main market factor. Qinglong coal mine is currently selling coal to Qianxi power plant consistently at a price of about 300 Yuan/ton. The price is comparatively low to coal mines, but coal prices for power generation tend to depend on local government's regulation, and the bargaining power is weak for coal mines. Therefore, as long as the power plants in these areas keep steady production, Qinglong will supply coal to the power plants steadily.

4.4 Guizhou gas market

4.4.1 Gas consumption

As of 2009, the city gas supplies in the province are: coke oven gas 300 million m^3/year, natural gas (excluding Chitianhua's fertilizer production gas) 50 million m^3/year, liquefied petroleum gas 82,000 tons/year. Total population of the province's gas users is 3.58 million (Guizhou Province's total population is about 40 million), in which liquefied petroleum gas user accounted for 47.49%, manufactured gas user accounted for 49.38%, natural gas user accounted for 3.13%. The detailed data are shown in Table 15.

Table 16. Population of gas user in Guizhou Province in 2009

No.	Gas source	Gasification City	Gasification Population (million)	Proportion
1	Manufactured 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	Mine gas	Liuzhi	4.9	
3	LPG		169.97	47.49%
3.1	LPG Cylinder	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%

4.4.2 Gas demand forecast

Guizhou gas market is consisted of the following key demands:

1. Gas demand for urban living: It is used mainly for residential cooking and water heating, and is a prior target in gas supply arrangements and ensuring continuous and stable supply. Natural gas has the advantages like low price, high heat value, good safety and environmental performance, and is the preferred fuel for civilian gas. During the twelfth 5-year program, the ration for resident's gas consumption is 500 X 4.18MJ/person-year (i.e. 2090 MJ/person. year).

2. Gas demand for commercial, public buildings: This includes the gas needed to support productions, operations and living of public buildings and facilities

(such as hotels, schools, etc.) of urban and rural residential areas, as well as the agencies, and research institutions.

3. <u>Gas demand for industrial users</u>: This includes coal-substituting gas used in industrial heating and production boiler and power plant boiler, heat supply required in manufacturing process (such as tobacco drying, ceramics, etc.), and the demand for gas as a chemical material (such as using methane as a raw material to produce chemical products).

4. <u>Gas demand for car users</u>: In the "Twelfth five-year program" period, Guizhou Gas Group has taken into account such factors as the size of cities, and focused on considering and planning for room of development of gas vehicle users (Guiyang and Zunyi of Guizhou Province, and other seven prefectures and cities).

Table 17. Gas demand forecast for Guizhou in the "Twelfth five-year program"

	Gas Consumption for Various types of gas users across the province (100 million cubic meters/ Year)									
	Civilian		Public buildings		Industry		Car		The sum of all types of users	
Region	*2011*	*2015*	*2011*	*2015*	*2011*	*2015*	*2011*	*2015*	*2011*	*2015*
Guiyang	0.85	1.31	0.68	1.96	2.95	13.04	0.58	0.77	12.8	65.38
Bijie	0.47	0.74	0.38	0.6	0	2.94	0.01	0.01		
Other regions	3.03	4.93	2.42	5.24	0	32.19	1.43	1.65		
Total	4.35	6.98	3.48	7.8	2.95	48.17	2.02	2.43		
Note: In this table, Bijie and Guiyang are listed separately because they are the nearest gas supply targets from Qinglong Coal Mine area.										

The table shows that in the period, the growth of gas demand in industrial and commercial sectors will be particularly strong. See the chart below for details.

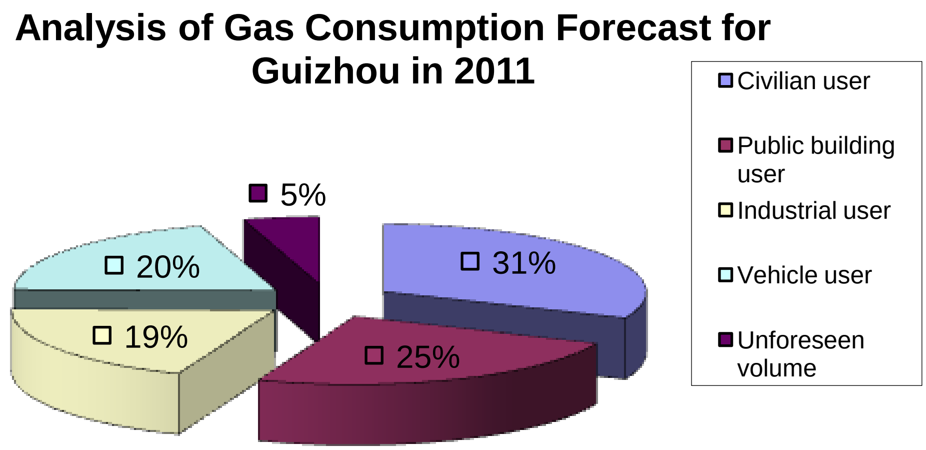


Figure 8. Analysis of Gas consumption forecast for Guizhou in 2011

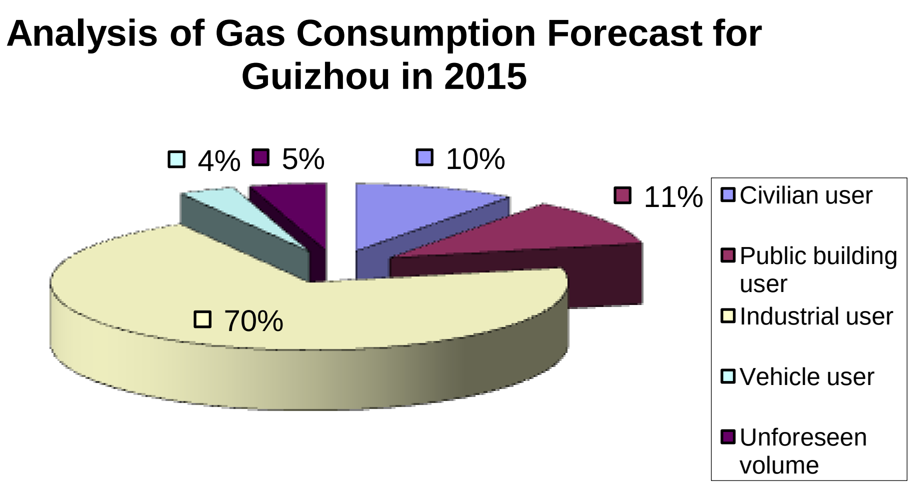


Figure 9. Analysis of gas consumption forecast for Guizhou in 2015

The growth in vehicle gas consumption is very small from 2011 to 2015. The reason might be: Guizhou lacks of natural resources, 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, so under the circumstances of limited gas supply, other key areas will be given priority, such as civil, industrial and so on. This does not mean there is no market for vehicle gas. On the contrary, it was the limited resource that limited the size of the market.

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

4.4.3 Gas Supply

According to Guizhou Gas Group's plan, natural gas will become an important source of Guizhou’s gas supply; natural gas 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 in Guizhou Province’s Long-distance pipeline will reach 1.75 billion cubic meters. In addition, Guizhou Gas Company, Petro China, and other enterprises in Guizhou will supply liquefied natural gas of about 376 million cubic meters per year, and compressed natural gas of about 11 million cubic meters per year. Other gas sources include manufactured 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 demand for gas is expected to 6.538 billion cubic meters, therefore there is a huge gap. If coal mine gas can be purified to make CNG/LNG, it will function as an important supplement to gas supply of natural gas in a certain area. If the price is competitive, Guizhou itself will become a huge market.

4.5 Electricity market

4.5.1 Guizhou Electricity Market Situation

By the end of 2010, Guizhou Power Grid has centrally dispatched 27.316 million kilowatts of installed capacity, of which hydropower's installed capacity is 10.176 million kilowatts, accounting for 37% of total installed capacity; thermal power's installed capacity is 171.4 million kilowatts, accounting for 63% of installed capacity. Please see Table 19 for details.

Table 19. Summary of Guizhou power grid's regulating units' installed capacity

Unit: ten thousand kilowatts

Thermal Power Plant Name	Installed Capacity	Hydro Power Plant Name	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 Station	8.4

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**		

For details about electricity output of Guizhou in recent years, please see Figure 10: (Source: "Guizhou Yearbook")

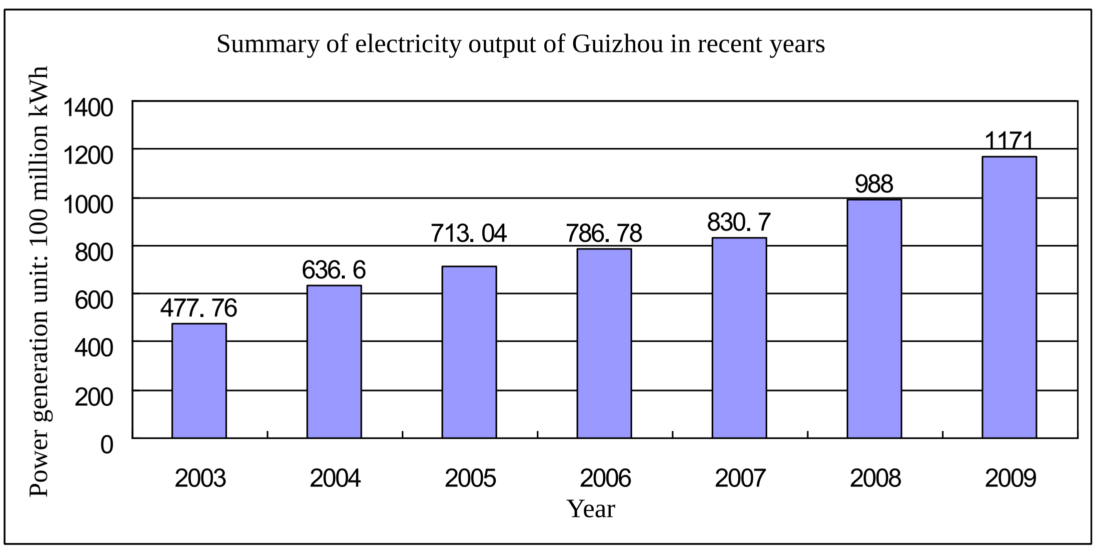


Figure 10. Summary of electricity output of Guizhou in recent years

As one of the key provinces in "West to East Electricity Transmission" project, Guizhou's electricity output in recent years is shown in figure 11.

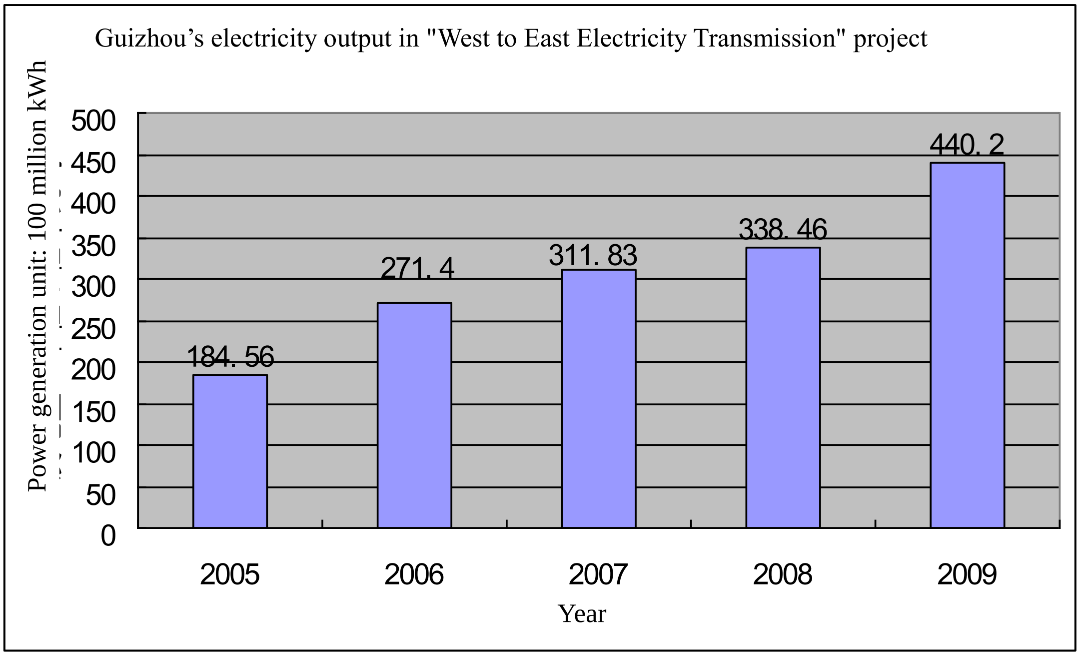


Figure 11. Guizhou’s electricity output in "West to East Electricity Transmission" project

4.5.2 Forecast for Guizhou’s Electricity Market

In recent years, with the sustained rapid growth of Guizhou’s local economy, the demand for electricity has continued to be strong, and it is in urgent need for new or extension of energy comprehensive utilization and power generation projects, to ease the region's stress on power supply. In addition to the factor that provincial economy continued its upward trend, other factors that are driving demand for electricity also include development of urbanization and rising living standards of urban and rural residents, and upgrade of residential consumption structure. Although technology advancement, environmental protection and energy saving will inhibit the demand for thermal power, however, the proportion of energy, raw materials, and heavy industry will increase in the economic development of Guizhou Province, so it is safe to predict that the province's electricity demand will rise. It is also expected that in the "Twelfth five year program" period, China Southern Power Grid and the demand for energy from other provinces will also boost demand for electricity from Guizhou (See Figure 12 below).

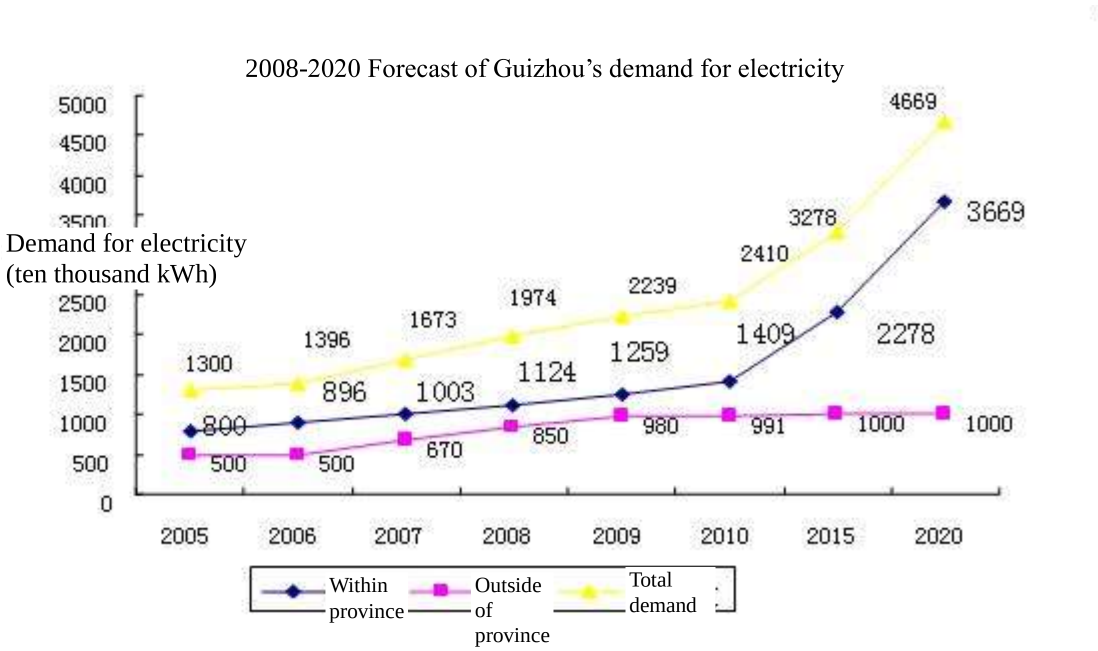


Figure 12. Forecast of Guizhou's demand for electricity

4.5.3 Guizhou electricity dispatch and pricing

Guizhou Province is covered by China Southern Power Grid. China Southern Power Grid Co. Ltd. was formally established and began operation on December 29, 2002, and became one of five state regional power grids. The business extends to five provinces (district) including Guangdong, Guangxi, Yunnan, Guizhou and Hainan, and is responsible for investment, construction and management of the power grid in south region, and conducts related business operations of power transmission and distribution.

For the country's current tariff system (including sales price of electricity and feed-in tariff for power plants), in principle, the price is based on provincial power grid, and goes with the grid price which will be set by the province. It 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 basically 0.3131 Yuan/kWh, and hydropower grid tariff is 0.2374-0.277 Yuan/kWh. The grid's electricity sales price is different according to users. For industrial users, such as coal mines, the average price is about 0.53-0.7 Yuan/kWh, and price changes with actual consumption; the greater consumption of electricity, the cheaper the price.

4.5.4 Market potential for CMM power plant

As shown above, the power plants in Guizhou that are connected to the grid for dispatching are all large-scale thermal power or hydropower plants. Because of the limitation in capacity of Guizhou's CMM, the potential to realize grid connection of large-scale gas power generation plant is very small. Therefore, in respect to availability and stability of power supply, the power grid company certainly tends to purchase from large thermal power or hydroelectric power plants. However, in order to promote the use of CMM, the Chinese government developed preferential policy to encourage gas power generation and grid connection: For output of gas power plants, in principle, the electricity of gas power plants should first be supplied for self-consumption in the mining area; for any surplus that need to feed into grid, the power grid companies not only will give priority to grid sales, they will also provide convenience to connect them into system, and invest and construct project to link grid to public link point; the grid tariff of electricity from gas power plant will be settled according to price of grid connection for biomass power generation projects, and will provide subsidies 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 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 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 of CMM power plants failed to go through normal approval procedures and did not comply with national procedure 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 power grid to co-ordinate 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 un-stable methane concentration, power generators of some power plants do not work stably with frequent start and stop. This poor operational reliability imposes poten-tial hazard to coal production safety and stable grid operation, which makes it diffi-cult for power grid to conduct normal operation and dispatch.

Based on the interviews with Qinglong mine's management, the above factors limit the initiative for coal mines to utilize the excess gas by adding power generation units. The coal mine plans to increase 2 generating units to further increase the power supply for self-consumption, and to meet the object of generating enough power for basic needs of coal mine. Therefore, if Qinglong Coal Mine will consider power generation, it must real-ize grid connection of its electricity.

5.0 Technical solutions for gas utilization

The main component of CMM is methane, whose heat value is equal to natural gas[3], and can be mixed with natural gas for transportation and use. Moreover, gas will not gener-ate any exhaust gas after burning besides CO2, and is a clean and cheap fuel for industri-al, chemical, power generation and civil living. The heat value of CMM determines its potential use value, whereas its heat value is related to content of methane (CH4). It can be said that the means of CMM utilization depends largely on the concentration of me-thane.

5.1 Selection of utilization method

For assessment of CMM utilization methods, we should consider not only the chemical and physical characteristics like concentration and stability of methane contained in ex-tracted gas, but also the impact on the socio-economic environment. It should be based on analysis of gas sources, considering the exploitation condition of local resources, market conditions and laws and regulations, to choose the most appropriate ways of uti-

[3] Specifically, the heat value of 1 standard cubic meter CMM gas is equivalent to 1.13kg of gasoline, 1.21kg of stand-ard 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.

lization.

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"[4] (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 gas 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 more and more coal mining enterprises, with proven economic, safety performance in practice; the Chinese government has released a safety standard for low-concentration gas utilization, and in essence, recognized the utilization method[5].

The Guidance publication studied 240 gas utilization projects around the globe in operation, under construction or plan, and summarized the potential uses of CMM with methane concentration of 30%-100%, the uses 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 guide compared potential use patterns of medium to high concentration gas, and described the way for purification and destruction (not use) of low concentration gas (including Ventilation Air Methane) (see section 4.4 of the General Report).

Table 20. Comparing methods of using coal mine gas

Use	**Application**	**Advantage**	**Weakness**
Power	Gas power genera-	• Proven technology	• Susceptible to in-

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

[5] It should be noted that the standard for high concentration and low concentration gas defined in the "solution guide" is different from the previous defining standards and norms of China's coal mine safety code. In the past, China's coal mine safety code defined high concentration gas as those with concentration of greater than 25%, and low concentration gas as those with concentration of less than 25%. According to coal mine safety regulations, the gas with concentration of less than 25% cannot be stored and transported, let alone utilized. However, the "Temporary standard of CMM (coal mine gas) emissions " (see below) effective on July 1, 2007 and the new version of "Coal Mine Safety Regulations" (see below) effective on March 1, 2010 has updated regulations in this regard, and resulted compliance of the "solution guide".

Use	Application	Advantage	Weakness
Generation	tion units, for self-consumption or feet to the grid	• Waste heat recovery, supply heat for the mine area, and miners' bathhouse, and provide thermal energy for heating and cooling	fluence 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	• Equivalent of natural gas • Profitable in areas of high pricing • Good choice for places with good pipeline infrastructure	• High standard for pipe cleaning, high cost of purification • Only applicable for high-quality pre-extraction 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 household fuel, district heating and industrial boilers, etc.	• Low fuel cost • Regional benefits • Less demanding on purification	• High cost of delivery systems and maintenance • Concentration and 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

Use	Application	Advantage	Weakness
			emissions
Coalmine self consumption	Miner quarter's 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	• Recovered 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 acquisition.

5.2 Technology solution 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 on coal mine gas utilization. The country used energy-saving investment funds to construct 56 coal mine gas utilization projects, and put the extracted gas to supply residential gas, manufacturing of carbon black and formaldehyde and other chemical raw materials. In recent years, low concentration gas had raised growing concern on power generation. But in general, the ways to utilize gas in our country is relatively limited; the current utilization rate is less than 30%, and has the potential to be tapped further.

It should be noted that the low concentrations of gas might be caused by natural endowments of coalbed methane, wrong drainage method, or improper installation standards for drainage system. The latter will not only lead to low extraction 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 extracted 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.

Following is a brief introduction of different CMM utilization methods in China that are currently underway or under development, with consideration of their applicability to high and low concentration gas. Low concentration gas destruction is not in the scope of our discussion because according to recommendations of China's current "CMM (coal mine gas) emission provisional standard"8, only high concentration gas (> 30%) can be disposed by burning. Though the utilization technology of ventilation air methane has matured the destruction of ventilation air methane doesn't create direct economic benefits, but relies entirely on carbon credits from emission reductions. Because the "Kyoto Protocol" expires in 2012, the market outlook for carbon credits is still unclear, and the coal mines or investors are fairly cautious to pursue 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.

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.

5.2.1 CMM for power generation

Currently, the mainstream technology for gas power generation is to use internal combustion engines. In China, power generation 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.

[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

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 gas 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 concentrations 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, imported generators with high efficiency that can reach 4 kWh are typically used. This equipment is expensive, and the requirements for gas concentration and composition are 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 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 extraction through utilization" and "promoting mining through extraction" in coal mines. The 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:

9 According to statistics, China's installed capacity of gas power generation in 2008 reached 710MW, of which 64% are domestic units.

Coal seam or gob →Φ60 drainage pipe at multiple points→ Regulation tube for mix of different concentrations → Φ400 main pipe →Air pump for extraction and supply →Power plant →Generator →Voltage up conversion → Regional transmission lines → Voltage down conversion →Coal mine production and living facilities

Figure 13. Typical process route adopted by Guizhou's low concentrations gas power plants

5.2.2 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"[10] 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 gas pipelines are 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 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 valve to provide gas for terminal use (see below).

[10] 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.

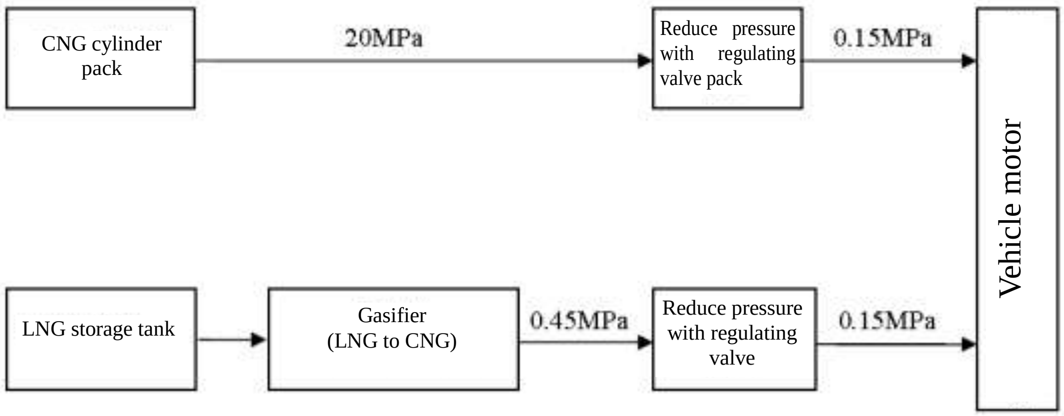


Figure 14. CNG - CNG, LNG - LNG vehicle fuel supply system diagram

Generally, adopting the above two gas supply approaches require to meet the following basic conditions: first, the extracted 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 extraction disruption; fourth, the gas supply terminals should have established LNG gasification stations or CNG regulation stations, to meet terminal needs for LNG "Gasification"[11] or CNG "Pressure reduction".

There are two forms of CNG filling stations, standard stations and son-mother 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 son-stations are built within the range of tens kilometers away from the mother 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 son-mother stations, with filling stations generally stay away from "Mother station", the liquefaction plant. Currently, LNG gas sources can only 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 to LNG. 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 l000m of volume, is 80 times higher than building a comparable LNG tank with 0.5Mpa of pressure and

[11] For "Gasification", there are two methods. One method is to use high-pressure cryogenic pumps to extract 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.

100m 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.

CMM-based-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. Its shelf life is 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[12] 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 CNG

<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>
<tr><td>CNG production process</td><td colspan="2">Feed gas →metering and regulation → purification → compression → dewatering→CNG Product</td></tr>
<tr><td rowspan="2">CNG supply process</td><td rowspan="2">CNG Product →filling station→tankers→regulation station/ filling stations→</td><td>→Town gas network → end-user</td></tr>
<tr><td>→CNG vehicles</td></tr>
</table>

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, economics and

[12] At 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.

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 (taking Guizhou as the background)

	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 bus company in year 2010.

5.2.3 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 extracted gas, but also improve the safety of mines. Secondly, the low concentration gas from gob and high concentration gas from pre-extraction area can be mixed to obtain the most suitable concentration.

A third method purifies the extracted gas through physical and chemical methods, and removes impurities (oxygen, nitrogen, carbon dioxide, carbon monoxide and hydrogen sulfide) through filtration, to obtain high concentration gas. Because the purification system is generally expensive, 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 deoxygenation 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, deoxygenation 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:

a. Pressure swing adsorption:

In most of the pressure swing adsorption (PSA) denitrification 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.

b. 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 deoxygenization.

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:

a. 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 first 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.

b. 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.

c. 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, 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.[13]. The Songzao Coal Mine in Chongqing is building a large project using CMM for produc-

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

tion 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.

5.3 Initial evaluation criteria for gas utilization solutions

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 access to 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 solutions regarding their progress in achieving the above purposes in the implementation process.

5.3.1 Financial efficiency evaluation

For evaluation of economic benefits of gas utilization solutions, 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 investor’s internal 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 solutions. 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 reduction generated by the project is 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 out of the following reasons:

1. Although China has successful CMM utilization CDM projects, and has obtained

regular income through carbon emissions trading. However, 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.

5.3.2 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 solutions. CMM utilization will not only improve production safety of coal mines and reduce greenhouse gas emissions, but also alleviate the current energy shortage, improve energy structure, and keep in line with national industrial policy requirements to develop 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 of 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.

5.3.3 Evaluation of emission reduction and environmental benefits

Methane is also 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 tons of carbon dioxide. In 2008, China used 1.6 billion cubic meters of CMM, and reduced emissions of carbon dioxide of 24 million tons. However, most of the CMM is discharged directly; this not only wasted resources, but also polluted 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 environment. 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 solutions, 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. CDM Board of the United Nations has provided a set of related methodology 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 solutions, and is not intended to make accurate quantitative estimates.

It is worth mentioning that, according to the logic of "promote extraction through utilization", expanding the scale of gas utilization is a strong push to gas extraction: 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 extraction can be regarded as indirect risk reduction measure for mine safety.

5.4 Obstacle analysis

In the following table, we use CDM "obstacle analysis" method of argument to list realistic, credible gas utilization options. Different from CDM argument, our aim is to investigate foreseeable economic, technical or operational obstacles in implementation process for different gas utilization technologies, rather than identify legal and regulatory obstacles. The "Decision to modify terms in <Coal Mine Safety Regulations>", signed and came into force on March 1, 2010, has relaxed gas use restriction against gas concentration of less than 30%. The solutions listed in the table are not faced with prohibitive obstacles in aspect of policies and regulations; in fact, they are in line with the state's industrial policies, and are beneficiaries of preferential policies of the state.

Here, we classify obstacles of implementation into "general obstacles" (A) and "insurmountable obstacles" (B). In the following risk assessment of specific alternative options (5.1.3 and 5.2.3), we will provide additional comments on these obstacles and risk factors.

The results show that for Qinglong mine, there are only two gas utilization solutions that are realistic and feasible: gas power generation or gas preparation of CNG.

Table 24. Obstacle analysis of alternative utilization solutions

Solution identification	Solution description	A: general obstacles; B: insurmountable obstacles
Solution i	Expand scale of the existing gas power plant to maximize the use of gas drainage volume increased with expansion of coal mine production. In addition to replace electricity purchased from China Southern Power Grid, the rest of produced electricity can be sold to the grid; waste heat can be recovered to replace boiler coal for plant area heating.	A: Expansion of gas power plant requires investment to purchase gas turbine and related equipment; this may face financial obstacles. Difficulty in connecting to the grid for power generation solution will limit further expansion of gas power generation scale; with the increase in coal mine's energy efficiency, the demand for electricity is limited; considering Guizhou's local climatic conditions, coal mine's demand for waste heat recovered from power generation is relatively limited; these factors will relieve the steam on "promoting extraction through utilization". In addition, domestic low concentration gas generator has low efficiency, and is not the optimal way to achieve efficient conversion and utilization of coal resources; with the China Southern Power Grid launching mandatory configuration of clean and renewable energy for thermal power resources and full range deployment within the grid, the uncertain factors for gas power generation and grid connection have been increased.
Gas power generation		B: None. This is a continuation of existing use patterns.
Solution ii	High concentration gas that is extracted can be put directly into gas tank, to produce CNG or LNG products. The products are then shipped outward through tankers to supply downstream industries for civilian use, vehicle fuel or chemicals; low concentration gas may consider for other end-use (such as power generation), or directly vented.	A: Investment is needed to build gas tank and purchase coal sources and production facilities of CNG and LNG;
Directly produce LNG or CNG		B: The gas drained from Qinglong mine is mostly low concentration gas; the volume of gas that can meet concentration requirement for gas tank safety input is very small. Therefore, the purchased equipments for CNG and LNG production will be left idle seriously; the investment cannot be recovered. If a large amount of low concentration gas is used for power generation, then this solution has no difference with solution i.
Solution iii	Use appropriate methods to purify low concentration gas that is extracted to produce CNG. The products are then	A: Investment is needed to build gas tank, purchase equipment for purification and liquefaction; some equipments need to be imported from abroad; prices are high; gas in liquid state needs to be transported,

Produce LNG after purification	shipped outbound by tankers to supply the province's transportation system as a vehicle fuel. For gas that does not meet the requirements of gas purification concentration, it may be put to other end use (such as for power generation), or directly vented.	stored under low temperature, and has the risk of stratification, leakage and heat evaporation, resulting in waste of gas source; the cost of vehicle conversion is high; it needs to negotiate with transport companies to ensure outward gas shipping, and there is risk of transportation disruptions caused by natural or human factors; relevant technical standards (building station, filling) has to be improved.
		B: Initial investment is high; production cost is very high; there are financing difficulties.
Solution iv	Use appropriate methods to purify low concentration gas that is extracted to produce CNG. The products are then shipped outbound by tankers to supply the province's transportation system as a vehicle fuel. For gas that does not meet the requirements of gas purification concentration, it may be put to other end use (such as for power generation), or directly vented.	A: Investment is needed to build gas tank, filling stations, CNG vehicle conversion plant, and acquire purification, compression, cleansing, dewatering units; filling stations involve complex process, and have high cost of construction, and large floor space (but the cost of construction is not the burden of coal mines); products need to be shipped with high-pressure tanker which involve safety risks and high unit cost of transportation; it needs to negotiate with transport companies to ensure outward gas shipping, and there is risk of transportation disruptions caused by natural or human factors; CNG filling time is long, and it is likely to form lines and congestion in filling operation; CNG market has yet been fully cultivated, and the future products of project are likely to face competition with long distance pipeline CNG, and so on.
Produce CNG after purification		B: None (assuming using technically feasible purification methods)

5.5 Power generation option

As a state-owned medium to large coal mine, Qinglong mine's drainage works have been developed according to standard, but most of the gas concentration is below 30%. For Qinglong mine's existing gas power generation projects, both high and low concentrations of gas are used, but the management believes that requirements of gas sources for high concentration gas power generation are too high. This leads to reduced stability of electricity output, so they are considering converting 2 units of high concentration utilization into low concentration utilization units. This further increases the capacity of low concentration gas turbines. According to this idea, in 2011, the project's implementation side (International Cooperation Center) commissioned the coal industry experts from Hefei Design Institute to develop a pre-feasibility study report. This chapter's analysis is based on data excerpt from economic and technical parameters of the pre-feasibility report.

5.5.1 Technologies and deployment schemes: power generation and electricity sale option

Gas power generation agrees with the general practice on gas utilization of Bijie region, where Qinglong mine is located. In September 2009, according to the requirements of the National Energy Administration, Bijie Development and Reform Bureau and Coal Administrative Authority commissioned the Provincial Coal Mine Design Institute to compile and report the "Gas mass utilization program of Bijie region". The program plans to install 166 units in Bijie region, and has installed 20 units of 500KW turbines; of which 15 units have been put into operation; the gas concentration being used is between 6-25%.

Qinglong mine currently has a gas power plant with installed capacity of 3400KW, including 4 units of 500KW, and 2 units of 700KW. In 2009, the gas drainage volume was 11.275 million m^3, with 3,427,188 m^3 used in gas power generation. The remaining volume is 7,847,900 m^3. In 2010, the total drainage reached 16.22 million m^3, of which only about 5.11 million m^3 was used in gas power generation; the remaining 11 million m^3 of gas was vented to air.

According to the following description of gas volume balance analysis, the program planned to add 8 units of 500KW low concentration gas turbines, with four 500KW units to be added in this phase, setting aside expanding spaces for four 500KW generation units. In the current project phase, there are four 500KW power generation units. Calculated according to 5500 hours of annual operating time and a methane consumption rate of 0.384Nm^3/KWh, the annual power output can reach 11 million kWh. Less the power needs for self-consumption (allegedly, Qinglong mine is in shortage of electricity), it has 9.81 million kWh for output, and will reduce methane emissions of 4.224 million m^3, and supply 8893 GJ of heat to outside, saving annually 3826 tons of standard coal.

Table 25. Gas balance

Years	2009	2010	2011	2012	2013
Total amount of gas extraction (ten thousand Nm^3)	1127	1600	2000	2600	3000
Total capacity that can be installed (KW)	3350	4756	5945	7728	8917
Existing capacity of generating units (KW)	3400	3400	3400	3400	3400
Total capacity that can be installed (KW)		1356	2545	4328	5517
Number of 500KW units that can be run at the same time		2.7	5.1	8.65	11
Number of 800KW units that can be run at the same time		1.69	3.18	5.4	6.9
Standard pure gas consumption per kilowatt-hour 0.384Nm^3/KWh (efficiency is about 26%)					

Considering that the current domestic units of 800KW, 1000KW are not as stable as a 500KW unit, Hefei Design Institute proposed to select "Shengdong" low concentration 500KW gas generator sets developed by Shengli Power Machinery Co., Ltd., a subsidiary of Shengli Oilfield. The supporting low concentration gas transmission system is specifically designed for safe usage of gas concentrations in the range of 6-30%. For gas transportation, they refer to the safety standards promulgated by the Chinese government, namely, "Safety system design specifications for low concentration coal mine gas pipeline" (AQ 1076-2009), "specification of safe transmission equipment for mixture of coal mine low concentration gas and water mist" (AQ 1078-2009), and so on.

Qinglong mine currently has 2 steam boilers, with evaporation capacity of 4t/h for a single unit, and pressure of 1.25MPa. The available waste heat for 500KW gas generator set is heat of flue gas. The flue gas heat for every 500KW unit can produce about 0.35t/h of steam with pressure of 0.8MPa. In this expansion project, four 0.35t/h steam waste heat boilers with pressure of 0.8MPa will be built to produce steam that will be fed to coal mine’s steam system for production and living purposes. They also selected 2 units of boiler feed pump, one in operation and the other as backup.

Qinglong mine area has a 35KV power substation. For the four 500KW units in the current project, the technical support to connect to the grid is assured.

5.5.2 Project financial analysis: power generation and electricity marketing option

5.5.2.1 Parameters input and assumptions: power generation and electricity marketing option

The following table shows the major parameters on which financial estimation analysis is based. The data all come from the project's pre-feasibility study report. Subsequent sections will report the results of analysis and forecast.

Table 26. Financial analysis of gas power generation: major data and parameters

No.	Project	Unit	Value
1	Number of generator sets	unit	4
2	Power of single generator	kW	500
3	Annual operation hours for power generation	H	5500
4	Annual power generation when achieving designed capacity	GW.h	11
5	Annual heat supply when achieving designed capacity	104GJ	1.23
6	Electricity sales price (Excluding VAT)	Yuan/ KWh	0.51
7	Heat sales price(Excluding VAT)	Yuan/ GJ	40
8	Annual consumption of gas (100%)	$104m^3/a$	422.4
9	Gas (100%) price	Yuan/ M^3	0.20
10	Plant consumption rate	%	10.8
11	Composite depreciation year	A	10
12	Residual value	%	3
13	Amortization of other assets	A	5
14	Repair rates	%	2.5
15	Water consumption	t/h	3
16	Water consumption (Excluding VAT)	Yuan/ T	1.20
17	Staffing	Person	12
18	Per capita wage	Yuan/ Person-years	50000
19	Materials fee	Yuan/ MW.h	20
20	Other costs	Yuan/ MW.h	15
21	Output tax rate for Sale of electricity	%	17
22	Output tax rate for Sale of heat	%	13
23	Urban maintenance and con-	%	5

	struction tax		
24	Education surtax rates	%	3
25	Income tax rate	%	25
26	Reserve fund escrow rate	%	10
27	Construction investment loan interest rate	%	6.80
28	Working capital loan interest rate	%	6.31
29	Financial benchmark rate of return	%	7.5
30	Calculation period for economic evaluation	a	11

5.5.2.2 Prediction result: power generation and electricity marketing option
The expected financial performance for implementation is as follows:

Table 27. Summary of financial analysis results for gas power generation

No.	Index Name	Unit	Index
1	Financial internal rate of return for project investment (after tax)	%	8.56
2	Financial net present value for project investment (after tax)	Ten thousand Yuan	85
3	Period for recovering for project investment (after tax)	Years	7.67
4	Financial internal rate of return for project investment (before tax)	%	11.04
5	Financial net present value for project investment (before tax)	Ten thousand Yuan	289
6	Period for recovering of project investment (before tax)	Years	6.97
7	Financial internal rate of return for project capital (after tax)	%	10.70
8	Total investment rate of return	%	6.91
9	Net profit ratio of project capital	%	12.95
10	Annual average after-tax net profit in the years of production	Ten thousand Yuan	72

It is shown from the above table: financial internal rate of return for project investment (after tax) is 8.56%, which is greater than the financial benchmark rate of return of project; financial net present value for project investment is greater than zero; period for recovering for project investment (after tax) is 7.67 years; and the total investment rate of return and net profit ratio of project capital are 6.91% and 12.95%. These indicators show that the profitability of this project is not strong, but still can be accepted.

5.5.2.3 Uncertainty analysis

Most of the data for the above financial evaluation is based on estimates, and there is a large degree of uncertainty. In order to assess the project's financial reliability, we can analyze how the changes in uncertain factors of the project will impact financial evaluation indexes of the project, and review the endurance of the project when these factors achieve threshold values.

Taking into account that the heat supply for this project is very small, we only considered factors like sales price of electricity, electricity sales, gas price and construction and investment to do the sensitivity analysis. The following table summarizes the impact on internal rate of return of the project when the above variables change 10% and 20%. The sensitivity analysis reflects a quantitative assessment of the financial risks of gas power generation. The qualitative analysis of other operational risks can be seen in the following section.

Table 28. Uncertainty analysis of gas power generation

Variables	**Magnitude of changes (%)**	**Financial internal rate of return for project investment (after tax) (%)**	**Sensitivity coefficient**
Electricity sales price	+20	14.13	3.26
	+10	11.41	3.35
	-10	5.53	3.53
	-20	2.31	3.65
Electricity sales	+20	12.88	2.53
	+10	10.75	2.57
	-10	6.27	2.67
	-20	3.86	2.74
Gas purchase prices	+20	7.53	-0.60
	+10	8.05	-0.58
	-10	9.06	-0.61
	-20	9.56	-0.59
Construction investment	+20	4.98	-2.09
	+10	6.64	-2.23
	-10	10.78	-2.61
	-20	13.47	-2.88

The above table shows that the project’s risk resistance capacity is not strong. This conclusion is also proven by break-even analysis: the break-even point calculated by relevant data of the year when the project achieves design capacity is 89.43%; while the break-even point calculated by relevant data of the year when the loan of capital investment is paid off (8th year of calculation period) is 70.80%.

5.5.3 Operational risk analysis

The following table shows the qualitative assessment of foreseeable operational risks upon implementation, and explains the response for high risk factors.

Table 29. Risk factors and measures of response

Risk Factors	**Evaluation**	**Risk Description/*High-risk response measures***
Market risk		
Electricity sold to grid	High	Increase self-consumption of electricity. Allegedly, there are power supply shortages in the mining area; and the demand in the power generation market is great. Currently, Qinglong mine's annual power consumption is 21 million kWh; and the existing generator sets and the proposed addition of generator sets will basically meet the demand for electricity. Thus, the role of mitigation measure is limited.
Receive subsidy on grid feed-in tariff	Medium	The state issued a series of preferential policies to encourage and support gas extraction and utilization projects, including grid feed-in subsidies.
Air security risks		
Gas supply shortage	Low	The annual gas drainage of the mine area is stable. Once the drainage pumping station is expanded in 2011, the pumping displacement can reach up to

		20 million m^3.
Volatile gas concentrations	High	High vacuum extraction concentration can be stabilized around 25%; low vacuum extraction concentration can be stabilized between 8% and 11%. Strengthen monitoring and install concentration regulating facilities. And mix high vacuum and low vacuum gas drainage before use.
Gas supply costs	Low	In order to improve mine safety, gas needs to be extracted from underground anyhow, whether it will be utilized, so the cost of gas can be excluded in this project.
Technology		
Reliability of power generation equipment	Low	The project uses proven domestic technology that features advancement, reliability, and applicability. The chance of significant changes is slim.
Inappropriate Equipment management and maintenance	Low	Enhance staff training, and designate personnel for management.
Environmental and safety risks		
The risk of 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 is unknown.
Pollution, noise risk	Low Risk	Project construction will strictly abide by national emission standards. Site has a comprehensive sewerage system. There is no resident households around, and there is no sensitive noise sources.
Financing risk		
Fund-raising capacity	Low	As a large state-owned enterprise, the mine has the ability to self-financing. This project does not use foreign loans and imported equipment; there is no exchange rate risk; the project will see quick results, and loan repayment time is relatively short. This also reduces the financing risk.
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 in place.
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	There will be no major changes in external building conditions (transportation, water supply, elec-

		tricity supply, telecommunications and building materials, etc.)
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.

5.5.4 Summary

The above financial analysis shows that the project is acceptable with respect to profitability, solvency and financial viability. However, the project's risk-resisting ability is not strong. Taking into account the huge uncertainty in grid connection of power generation, which will greatly limit the future scale of Qinglong mine's gas drainage and utilization, we are not optimistic about this option.

5.6 CMM purification and production of CNG

In this option, gas goes through separation, purification, and methane recovery to obtain natural gas. It is then compressed into Compressed Natural Gas (CNG), and shipped outbound as a vehicle fuel. It not only provides a highly efficient, high value-added new method in exploring gas comprehensive utilization for Qinglong mine. It can also serve as a demonstration project to promote emission reduction in high-emission transport sector. This project's implementation party (International Cooperation Center) has commissioned experts from Sichuan DKT Corporation to conduct pre-feasibility study for implementation. This chapter's analysis is based on data from economic and technical parameters of the pre-feasibility report.

5.6.1 Technology and development options

The solution is to effectively recover, purify, and concentrate the methane collected through high-vacuum gas extraction pumps (methane concentration in around 25%), and then compress the concentrated methane gas to produce compressed natural gas (CNG). According to an analysis of CMM data, through combination, comparison, and analysis of process units, we decided to choose the PSA process. First, special adsorbents are used to enrich methane in CMM. Then, oxygen is removed from the enriched methane by using a special absorbent. The deoxidized, enriched gas is purified and concentrated. Finally, the qualified product is compressed and made into CNG for delivery to CNG filling stations, or transported by tankers and supplied to the province's public transport facilities as alternative fuels.

Since Zunyi Bozhou Gas Company, a subsidiary of Guizhou Gas Group, built CNG filling stations (15000 m^3/ D) in Zunyi and put them into operation to serve the community in 2006, it has realized 150 CNG vehicle conversions. Guiyang Gas Design Co., Ltd., a subsidiary of Guizhou Gas Group, is conducting planning and design work for Guiyang's vehicle oil to gas conversion filling stations. The option proposed is to construct a CNG filling station, and also a filling sub-station that will be about 30 ~ 70km away from the device in new project (location is to be determined). A new CNG vehicle modification plant will also be constructed.

The production equipments in this option are divided into eight sections: gas pressurization, VPSA methane enrichment, methane-rich gas compression, deoxidation of methane-rich gas, VPSA methane concentration, natural gas compression, CNG products filling and storage, CNG filling substations. Water, electricity, gas and other utilities can be supplied from Qinglong mine's existing facilities.

The production scale is mainly decided by gas volume. According to production statistics from a ground high vacuum gas gathering station of Qinglong mine, under the normal production circumstances, the amount of gas extraction is: 6000Nm^3/h, the proposed gas processing plant capacity is 6000Nm^3/h. Under this presumptive condition, if methane content in the feed gas ≈ 25%, the methane content after CNG concentration will not be less than 94%. Assuming the methane recovery rate is 95%, it will produce CNG 1500 Nm^3/h. With annual production time of 8000 hours, the annual production capacity is estimated to reach 12 million Nm^3 CNG.

The CNG option's technical characteristics are:

1. High concentrations of oxygen in methane gas and high levels of dust will bring about a safety hazard to the production process of industrial production equipment. Because static electricity is likely to be generated in industrial production, and static clustering is likely to produce sparks, causing fire and explosion. In this regard, an adsorbent with good conductive properties is used. The adsorbent does not produce dust during operation, and can effectively conduct static electricity and transfer heat, thereby effectively preventing the possibility of spark by static clustering.

2. The solution uses special oxygen adsorbent that will only adsorb oxygen without causing loss of methane. Reducing the oxygen content in feed gas under explosion range will ensure the safety and stable operation of methane enrichment process.

3. For gas with different concentrations of methane, different gas separation and purification processes can be used for methane recovery.

4. Adding explosion suppression materials (National Fire Protection certification) to pipelines and empty towers will effectively remove potential static electricity in a timely manner, and avoid spark generation, to protect safe operation.

5. Special adsorbent is used to increase the separation factor of methane and nitrogen to above 3.3. In this way, methane concentration can be increased to 90% through adsorptive separation, and methane recovery rate is greatly improved.

6. For the pressure swing adsorption process being used to recover CMM, it features low investment, lower unit operating costs, high purity of compressed natural gas, simple and flexible production, low environment pollution, and wide applicable range of feed gas source.

7. In summary: With respect to feed gas conditions, safety in compressed natural gas production, stability of product quality and overall benefit, we propose to adopt the CNG option. This option has merits including fine quality of product (CNG), stable equipment operation, and easy regulation of system's production capacity.

5.6.2 Financial Analysis

5.6.2.1 Parameters and assumptions

The following table shows the major parameters used to calculate financial indicators. All of the data come from the pre-feasibility study report of this project.

No.	Project	Unit	Value
1	Annual sales, total operating costs	Ten thousand Yuan	1539
2	Gas processing capacity	Nm^3/h	6000
3	CNG product sales	Ten thousand Nm^3 year	1200
4	Sales price	Yuan/ Nm^3	2.5
5	Construction period	Month	12
6	Production period	Year	10
7	Fixed assets investment estimation of the project	Ten thousand Yuan	3731.76
8	Construction investment loans	Ten thousand Yuan	2612.23
9	Annual interest rate of construction investment loan	%	7
10	Own funds	Ten thousand Yuan	1119.53
11	Loan interest rate for working capital	%	7
12	Industry benchmark yield	%	12

13	Calculation period for economic evaluation	Year	10
14	VAT rates	%	13
15	Ratio between urban maintenance and construction tax and value added tax	%	5
16	Ratio between education surtax and value added tax	%	3
17	Income tax rate	%	25
18	Staffing	Person	67
19	Per capita wage	Yuan/ Person-years	50000

Table 30. Financial analysis of CNG preparation: major data and parameters

5.6.2.2 Result of predictions

Implementation of the program's expected financial performance is as follows:

Table 31. Key indicators for financial evaluation

No.	Project	Amount
1	Construction investment (ten thousand Yuan)	3731.76
1.1	In which: RMB (ten thousand Yuan)	3731.76
1.2	Foreign currency (U.S. $)	0.00
	Converted to RMB (ten thousand Yuan)	0.00
2	Interest in construction period (ten thousand Yuan)	89.24
3	Working fund (ten thousand Yuan)	300.00
4	Total investment of project (ten thousand Yuan)	4031.76
5	Construction period (year)	1.00
6	Total production period (year)	10.00
7	Annual sales income (ten thousand Yuan, year average)	3000.00
8	Total cost of annual sales (ten thousand Yuan, year average)	2102.47
9	Annual operating costs (ten thousand Yuan, year average)	1538.99
10	Annual after-tax profit (ten thousand Yuan, year average)	894.78
11	Annual tax payments (ten thousand Yuan, year average)	566.23
12	Annual income tax payments (ten thousand Yuan, year average)	298.26

13	Total annual profit tax (ten thousand Yuan, year average)	1461.01
14	Rate of return on investment (% year average)	33.36
15	Full investment after income tax	
15.1	Period for recovery of investment (year, static)	5.42
15.2	Financial internal rate of return (%)	19.15
15.3	Financial net present value (ic = 12.0%, ten thousand Yuan)	1100
16	Full investment before income tax:	
16.1	Period for recovery of investment (year, static)	4.38
16.2	Financial internal rate of return (%)	27.75
16.3	Financial net present value (ic = 1.20%, ten thousand Yuan)	2577
17	Own funds	
17.1	Period for recovery of investment (year, static)	5.62
17.2	Financial internal rate of return (%)	35
17.3	Financial net present value (ic = 1.20%, ten thousand Yuan)	1802

The above table shows:

(1) After completion of the project, the revenue of average annual sales can reach 30 million Yuan, the average total annual profit tax is 14.61 million Yuan, and average annual after tax profit is 8.9478 million Yuan (after tax).

(2) When industry benchmark yield is equal to 12.0%, the financial internal rate of returns for full investment before tax and after tax are 27.75% and 19.15% respectively; the static investment recovery period is 4.38 years and 5.42 years (including 1 year of construction period); and financial net present values are 25.77 million Yuan and 11 million Yuan.

From the above analysis of financial indicators, we can see that the economic return of the project is good, and the project is basically feasible from an economic point of view.

5.6.2.3 Uncertainty analysis

The following table shows the impact of four single factors of which the changes will influence financial internal rate of return (FIRR) (after income tax) for full investment, the factors include price of gas sales, amount of gas sales, gas purchase prices, and construction investment.

Table 32. Financial uncertainty analysis of CNG preparation

Variables	Internal rate of return (%)	Change rate of internal rate of return (%)	Net present value (ten thousand Yuan)	Change rate of net present value (%)
Normal circumstances	19.15		1100	
Gas sales price changes +20%	30.90	61.36%	3075	179.55%
Gas sales price changes -20%	5.73	-70.08%	-875	-179.55%
Gas sales volume changes +20%	29.99	56.61%	2917	165.18%
Gas sales volume changes -20%	6.92	-63.86%	-717	-165.18%
Gas purchase price changes +20%	18.16	-5.17%	942	-14.36%
Gas purchase price changes -20%	20.13	5.12%	1258	14.36%
Construction investment changes +20%	13.69	-28.51%	298	-72.91%
Construction investment changes -20%	26.68	39.32%	1901	72.82%

According to the uncertainty analysis, product sales revenue is the most sensitive factor. When gas sales price, which affects product sales revenue, is reduced for 20%, FIRR drops from 19.15% to 5.73%; when the same is increased for 5%, FIRR rises up from 19.15% to 30.90%. When gas sales volume, which affects product sales revenue, is decreased by 20%, FIRR drops from 19.15% to 6.92%; when the same is increased for 20%, FIRR rises up from 19.15% to 29.99%. Therefore, enterprises should pay attention to production costs control while increasing sales revenue. In short, the solution's financial risk is controllable, and implementation of the solution will not pose a major threat.

5.6.3 Risk factors and response measures

In the above text, we compared the consumption prices in the natural gas market, CNG and fuel oil market, and analyzed the market of natural gas. We believe that natural gas vehicles are more economical than gasoline, diesel, and LPG vehicles. Compared with electric vehicles and other alternative energy vehicles, its cost advantage is obvious, and is easier to use. However, the development prospects of CNG vehicles in the realm of city vehicles are faced with many potential risks.

Table 33. Operational risk factors and response measures for CNG preparation

Risk Factors	Evaluated level	Risk Description/High-risk response measures
Market risk		
Alternative fuels competition	Low	CNG is more convenient, clean and safe than other vehicle fuels
Construction of filling stations	Uncertain	
Vehicle modifications	Uncertain	
Difficulty in CNG outbound shipping by tanker	Low	Convenient site traffic
Gas source security risks		
Gas supply shortage	Low	The annual gas drainage in mine area is stable; after expansion of drainage pumping station in 2011, pumping displacement will be over 20 million m^3.
Unstable methane concentrations	High	Although the purification devices in this project are applicable to different concentrations of methane gas, and use a variety of gas separation, purification processes for methane recovery, the project presume to use gas with concentration of over 25%.
Gas supply costs	Low	In order to improve mine safety, gas needs to be extracted from underground anyhow, whether it will be utilized, so the cost of gas can be excluded in this project.
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	Medium	Integrate equipment in the

concentration for CNG		extraction, collection and storage system so as to regulate gas quality
Environmental and safety risks		
"Three wastes" discharge	Low	Purification units don't produce polluting gas source in normal production; condensate that is generated will be piped into sewage treatment system and will not be discharged to outside; discarded adsorbent and catalyst can be recycled to suppliers.
Noise hazards	Low	The largest noise source is CNG compressor. Special measures can be taken to control noise levels below environmental protection standards.
Safety risks (hazardous substances, electrical hazards, etc.)	Low	The only safety risks are methane and high- and low-voltage motors. T obvious and potential risk factors in production will be taken care of by necessary preventive measures, in accordance with the norms, regulations, standards, which are integrated into the overall design.
Financing risk		
Loan risks in construction period	Unknown	Coal mining enterprises lack confidence and ability to build projects by raising fund.
Loan risks in operation period	Unknown	Working capital that is required to operate is not enough and bank loan is needed.
Policy risk		

The risk of policy changes	Low	The project conforms to relevant national policies, such as recycling economy, energy cascade utilization, clean production, continuous automation, and other environmental protection and energy saving measures.
Collaborative risk		
Collaboration in production and services	Low	
	Unknown	Need to negotiate settlement for outbound tankers arrangement with transportation company.
	Unknown	Need to negotiate with urban public transport companies regarding filling station construction and vehicle modification.

5.6.4 Summary

The above analysis shows that the CNG end-use option has good cost-effectiveness and resistance to financial risks, and there is no uncontrollable operational risk. But implementation of this option is faced with some degree of collaboration risk (associated mainly with issues like negotiating settlement for outbound tankers arrangement with the transportation company and negotiating with urban public transport companies regarding filling station construction and vehicle modification). Weighing the risks and benefits, we believe that the prospects for this option is better than gas power generation, and recommend to the Qinglong mine management to seriously consider this option.

6.0 Comparison of end-use solutions

6.1 Financial benefits comparison

A. Investment comparison

The content for a comparative evaluation of project investment options should include two aspects: 1) a technical and economic analysis and evaluation of the single technical scheme or construction investment scheme, and 2) a comprehensive technical and economic analysis, argument and evaluation of the overall project construction investment scheme. The former has been introduced in 5.1.3 and 5.2.3 respectively; here, we use a simplified "cost - benefit analysis" method, to compare the financial indicators associated with overall return of investment for the above two options, and to examine the impact of critical cost and yields which influences the overall financial benefits of the project in the period from construction to operation (service life) (see table below).

Table 34. Financial indicators comparison regarding investment returns for gas power generation and gas manufacturing options

Indicator Name	**Unit**	**Power generation**	**CNG**
Service life	Year	10	10
Fixed asset investment budget estimate	Ten thousand Yuan	1825	3731.76
Working capital	Ten thousand Yuan	26	300
Financial internal rate of return for project investment (after tax)	%	8.56	19.15
Financial net present value for project investment (after tax)	Ten thousand Yuan	85	1100
Period for recovering for project investment (after tax)	Years	7.67	5.42
Financial internal rate of return for project investment (before tax)	%	11.04	27.75
Financial net present value for project investment (before tax)	Ten thousand Yuan	289	2577
Period for recovering of project investment (before tax)	Years	6.97	4.38
Financial internal rate of return for project capital (after tax)	%	10.70	35
Annual average after-tax net profit in the years of production	Ten thousand Yuan	72	894.78

The table above shows that the financial net present value of investment for the two options are far larger than zero, indicating that both options have the potential to make profit; but CNG's overall economic performance is far better than power generation, such as a higher level of profitability (see financial net present value of investment, contrast of total rate of return on investment), a stronger ability on finance (high financial internal rate of return for investment), and a shorter investment recovery period. On the other hand, CNG requires a much larger size of fixed and working capital than those of power generation.

B. Comparison of financial uncertainty

Through sensitivity analysis and comparative analysis, we examined these two options' financial ability to resist risks. The purpose is to test the overall economic performance of each option by changing the key operating parameters within a reasonable range. In this way, we will know which option can better attract investment in terms of returns when the operating environment changes.

Here, we examine the following common factors that will influence the internal rate of return of both the power generation and gas manufacturing options:

- Sales price (electricity sales price, gas sales price)
- Sales (electricity sales to grid, CNG sales volume)
- Gas supply prices
- Construction investment

Assuming that the above parameters change within the range of -20% to +20%, the changes of internal rate of return for both end use options are listed in the following table.

Table 35. Financial sensitivity comparative analysis of alternative end use options

Magnitude of changes	Power generation		Gas manufacturing	
	Variables (Power generation)	Financial internal rate of return on investment after income tax (%)		Variables (CNG)
+20	Electricity sales price	14.13	30.90	Gas sales price
+10		11.41	25.15	
-10		5.53	12.76	
-20		2.31	5.73	
+20	Electricity sales	12.88	29.99	Gas sales
+10		10.75	24.68	
-10		6.27	13.29	
-20		3.86	6.92	
+20	Gas purchase price	7.53	18.16	Gas purchase price
+10		8.05	18.66	
-10		9.06	19.64	
-20		9.56	20.13	
+20	Construction investment	4.98	13.69	Construction investment
+10		6.64	16.23	
-10		10.78	22.58	
-20		13.47	26.68	

C. Operational risk comparison

Table 36. Total number of risk factors and their ratings for end use options

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

6.2 Emission reduction benefits comparison

Due to data constraints, we cannot make an accurate comparative analysis regarding the comprehensive environmental benefits of gas power generation and gas manufacturing end use options. We only make some rough estimates to greenhouse gas emission reduction potentials of the two utilization solutions, and take them as a reference to compare their emission reduction benefits. Here we consider only the amount of gas consumed in project's production process, assuming the gas will be completely vented in the baseline scenario. We do not consider the energy consumption in the project's implementation, or the fuel substitution achieved by the project's products (electricity and CNG).

- ✧ Gas power generation option: In the current project phase, there are four 500KW power generation units. Calculated according to 5500 hours of annual operating time, with a methane consumption rate of 0.384Nm^3/KWh, the annual power output can reach 11 million kWh. Less the power needs for self-consumption, it has 9.81 million kWh for output, and will reduce methane emissions of 4.224 million m^3, and supply 8893 GJ of heat to outside, saving annually 3826 tons of standard coal, which is equivalent to 65,714 tons of CO2 emission reduction.

- ✧ Manufacturing CNG from gas solution: With installed production capacity of 6000Nm^3/h CMM processing, and 1500Nm^3/h of CNG manufacturing capacity (equivalent to standard gas), if the annual production time is 8000 hours, the annual production capacity of this project will be 12 million Nm^3 CNG (equivalent to 171,360 tons of CO2).

6.3 Social and economic benefits comparison

Whether it is gas power generation or gas manufacturing, their objectives are both aligned with the policies of energy conservation, cleaner production, and promoting safety in coal mines and comprehensive resource utilization through "promoting extraction through utilization" and "promoting mining through extraction". However, the gas manufacturing solution seems to have more potential, with significant social and economic benefits, such as: enhancing national energy security with alternative energy, extending the industrial chain to increase the value of the coal industry, and promoting local employment.

6.4 Conclusion

Qinglong mine is a stable active mine and is expected to reach its design capacity (1.2 m t/a) in 2014. Current surplus CMM after being utilized for power generation is more than 11 million m^3 and the amount will increase to 17 million m^3 in 2014. However, power generation is unlikely to consume most, not mentioning all the surplus gas due to constraints to sell electricity to the grid. Through this pre-feasibility study, we find CMM to CNG has much better financial performance compared to power generation. This option has the potential to utilize most of the surplus CMM. We recommend investors to engage with Qinglong mine and co-develop a full scale feasibility study in order to carry out this project.

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

1. For Qinglong Coal Mine, both of the above utilization options can promote coal mine safety in production, improve utilization efficiency of coal resources, protect the atmosphere, and are technically feasible with adequate gas supply security. Looking from the economic, technical and other micro level aspects of project, the two options have their respective merits and weaknesses: power generation has advantages like small investment, quick results, short payback period, and a technologically highly-skilled mine management. For the gas manufacturing option, while the initial investment is large, the cost of financing is high and the investment recovery period is long, but the long-term income prospects and the return on investment are higher than the power generation option. At the moderate and macro level, gas manufacturing's comprehensive economic and environmental emission reduction benefits are superior to power generation, as its prospect of development is much wider.

2. The biggest operational risks associated with implementation of the gas manufacturing option include negotiating settlement for outbound tankers, arrangement with the transportation company, and negotiating with urban public transport companies regarding filling station construction and vehicle modification, as well as financing risks in project construction. The biggest operational risk associated with implementation of gas power generation is to negotiate settlement with the power grid company for arrangement of grid connection.

3. Although the gas power generation option is easy to manage, because of its low energy conversion efficiency, it is not the best way to use gas resources. Gas manufacturing is a kind of technology innovation for Qinglong mine, and it has broad market prospect; but because of its technology involvement and complex transaction processes, its learning costs, expected management, and transaction costs are higher than power generation.

4. The primary purpose of gas extraction and utilization is to promote safety in coal mine production. Because the natural gas market is enormous in Guizhou where oil and gas reserves are limited and there is difficulty in grid connection for gas power generation, and coal mine's own demand for electricity is limited, we have reason to believe that gas manufacturing has more potential than gas power generation.

5. For Qinglong mine, the gas utilization option proposed by two design institutes may be complementary rather than mutually exclusive. This is because the gas concentration applicable to power generation and gas purification do not overlap: the gas purification scheme uses gas with concentrations mainly of above 25% extracted through high-vacuum drainage, then the low concentration gas can be used for power generation; while the power generation solution's coverage of concentration requirement seems to be bigger, where high vacuum and low vacuum drainage of gas can be mixed for use. Thus, if funding available is abundant, power generation and gas manufacturing can be considered in parallel to optimize allocation for different concentrations of gas resources in two ways of utilization. One of the potential advantages of an optimized parallel solution is that the gas power generation plant can supply electricity to the gas manufacturing plant, to partially alleviate the pressure on gird connection. The potential risk will be increased cost in internal coordination (coordinating the demand and relationship between gas power plant and gas manufacturing plant).

6. Compared with gasoline, diesel and LPG vehicles, CNG vehicles have irreplaceable advantages in terms of environmental protection, economy and safety and are more feasible in terms of technology maturity than LNG vehicles. However, LNG's advantage in storage is obvious, gas filling is faster than CNG vehicles, and is likely to compete with the gas manufacturing CNG option. Combined with the natural gas utilization plan of Guizhou ("Send gas from Sichuan into Guizhou," "Send gas from Myanmar into Guizhou"), the possible trend for development of a natural gas vehicle industry in Guizhou could be as follows: In the early development stage, use CNG-gasoline dual-fuel natural gas vehicle conversion technology to launch the car market, and gradually build a filling station system, and the modified models would be mostly gasoline-powered bus and taxi. In the middle development stage, the focus will be direct introduction of CNG-only natural gas vehicle. In the long term, with the introduction of LNG gas supply and maturity of LNG technology, the process would achieve common development of CNG vehicles and LNG vehicles. For Qinglong Coal Mine, development of a CNG manufacturing project in Guizhou requires attention and focus on the mid and long term trend of "oil to gas conversion" market in the transportation system, in order to position in favorable standing in the increasingly competitive automotive fuel market.