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Feasibility Study of Coal Bed Methane Production in China

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China University of Petroleum, Beijing

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Project Name

Feasibility Study of Coal Bed Methane Production in China

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Preface

This report is a very special, if not, unique report, in that it represents the results of a very comprehensive study and survey of all prospective Coal Bed Methane (CBM) production sites in China. As far as we can ascertain, this is the first time that on such an unprecedented scale, prospective CBM sites have been investigated in terms of their geological structure, gas production possibilities, exploration and production costs, suitability of various drilling techniques, remoteness from markets, overall economy and impact on society. This also included taking a view on fiscal policies and incentives from the Government.

In this respect, the most outstanding product of this study is that the study has been able to identify the most attractive sites for CBM production in China and, in fact, make a ranking in terms of overall attractiveness and the amount of any subsidy required to make CBM production feasible. The report also shows that any such subsidy is recovered quickly from the benefits that that CBM production brings for China.

The study is not limited to China. In fact, a great deal of the research has been aimed at finding the most productive CBM sites in the world, understanding why they are so productive and drawing lessons therefrom for application in China, as far as conditions in China would allow. In order to understand why foreign sites have been successful in CBM production, it was necessary to delve into the geological characteristics of foreign sites (as far as available), the drilling and production technologies applied, the infrastructures available and any fiscal policies that the corresponding foreign (local) Governments would apply to foster the development and expansion of CBM production.

Given the above, it was only natural that the study also embarked on a technological and financial comparison of various CBM drilling technologies as well as a study into historical and still existing bottlenecks in the development of CBM prospects in China.

In a market driven economy, the question whether CBM production is feasible, is determined by economics. For all the sites studied, therefore, economic analyses have been made, bringing together all determining factors such as investment, exploration and production costs as well as remoteness from markets, the presence of infrastructure and fiscal policies, resulting in an overall assessment of a site's "attractiveness for CBM production".

In all this, it goes without saying that this report is predominantly aimed at the Chinese Government in order to assist it in the decision making process related to the development of CBM production sites, as well as at any oil and gas companies that want to explore for and produce CBM. However, this report is also meant for all of those (students, experts and managers in related industries) who want to get a better understanding of CBM, CBM production and the factors that govern its feasibility.

Acknowledgements

Although the project of The Feasibility Study of CBM Production in China is carried out by the China University of Petroleum, Beijing, this work would not have been possible without the contribution and support from others.

In this respect we would like to mention:

- The experts that have already been working on CBM before us and to whose research we are referring and whose results we are quoting in this report. Among these pioneers who initiated the CBM industry in China and to whom we are greatly indebted, we particularly like mention: Jie Mingxun, Li Jingming, Zhao Xianzheng, Liu Xianfa, Sun Maoyuan, Zhang Xinmin, Ye Jianping, Zhao Qingbo, Qin Yong, Wang Hongyan, Zhang Suian, Fan Zhiqiang, Zhang Fudong
- Mr. Bert Bekker, EU Manager Natural Gas of the EU-China Energy Environment Programme to whom we are very grateful for his great support and assistance. Mr. Bekker's friendly encouragement and professional guidance has accelerated the completion of the project, and has even influenced the direction of our future research.
- Mr. Wang Shenghui, China Manager Natural Gas of the EU-China Energy Environment Programme to whom we are very grateful for his great hard work for the successful implementation and finish-up of the project with his excellent professional quality and diligent, pragmatic work style.
- The Energy Bureau of the NDRC for its advice and support
- PetroChina Research Institute of Petroleum Exploration and Development-Langfang and China United Coal Bed Methane Corp. Ltd. for their supports.
- The leaders and their related departments of the China University of Petroleum, Beijing for their encouragement and support.

Project Team

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Project Introduction

The EU-China Energy and Environment Programme

Established by an agreement between the European Community and the Government of the People' Republic of China signed on April 3rd, 2002, the EU-China Energy and Environment Programme (EEP) is a reflection of both sides' desire to further strengthen EU-China cooperation in the energy sector.

Within the above context, the overall purpose of the EEP is to promote "a sustainable use of energy, whereby Chinese energy users will have a secure energy supply at improved economic, social and environmental conditions, thus contributing to improved environmental quality and healthy conditions".

The EEP aims to achieve the following:

- to foster the cooperation between Chinese and EU industries in China's energy markets
- to strengthen the security of energy supply in both China and Europe
- to protect the global environment in line with international objectives (in particular in the context of climate change), and to ensure sustainable development

The EEP is designed to support these overall strategic aims. Within this context, the EEP is represented by four components:

- Energy Policy Development (EPD component)
- Improving Energy Efficiency (EE component)
- Increasing the use of Renewable Energy (RE component)
- Increasing the use of Natural Gas (NG component)

Feasibility Study of Coal Bed methane

Feasibility Study of Coal Bed Methane in China is one of the projects which are funded by the EEP and whose research team has been selected by inviting public bids. The purpose of the program is to evaluate the technical and economic feasibility of CBM production in China. This project began on 25 June 2007 and ended on 25 March 2008 with total budget of €433,000. The project was managed by the NG component of EEP. The execution of the study was awarded to the **China University of Petroleum, Beijing.**

Research Background

The rapid economic growth in China has led to a tremendous increase in its energy consumption. As a net oil importer since 1993, China's dependence on foreign oil supply has been rising continuously and reached 47% in 2007. The heavy dependence on the foreign oil has brought about two challenges to the Chinese economic development: Firstly, the dramatic fluctuations of the international oil prices are impacting on China's economic development; secondly, international political or economic events may lead to interruptions in China's foreign oil supply, and as these have become so substantial, these events may have dire consequences for China's economy, These two challenges are of national strategic importance, in the sense that they may impact the country's destiny and even threaten its political and social stability.

The increasing demand for energy combined with an insufficient domestic supply of crude oil and increasing dependence on international energy compel China to use energy sources other than of oil, such as coal, natural gas, nuclear energy, hydropower, wind power, solar energy and coal bed methane. Apart from coal, natural gas resources are most abundant but are used at a very low scale in China. However, as natural gas is a reliable, economic and, above all, clean energy source, it is expected that the exploration and production of natural gas will grow substantially in the near future. The development of nuclear energy is still in its initial stages. As it will take a long time and massive investments to develop nuclear energy, it is unlikely that it will play a dominant role in near future. Hydroelectricity is a clean source of energy, but the construction time is long and the required investments are great, moreover its application may not be without environmental problems. Therefore, the application of hydroelectricity on a large scale also seems unlikely. Wind power, solar energy and coal bed methane gas are currently used in very limited amounts and these are therefore merely regarded as a supplementary source of energy. Thus, in order to support the economic development, the abundantly available coal has remained and will be the most important source of energy in China's energy structure for the foreseeable future. China's current production amounts to more than 2 billion tons per annum.

China's coal reserves, from energy sufficiency point of view, can meet the demands of its economic development. However, the rapid development of the coal industry and the enormous coal production has caused serious social and environmental problems. In this respect the combustion of coal will give rise to the emission of particulate matter, CO_2, SO_2, NO_x and other harmful gases, resulting in serious air pollution, especially in the (low-stack) residential areas. The emission of CO_2, a greenhouse gas, will lead to global warming and as China has become a dominant player in this field; its contribution to global warming is not insignificant. An aggravating factor hereby is the fact that most of China's coal burning facilities are burning coal with a very low efficiency, thereby producing more CO_2 than strictly necessary. In addition, also the production and transportation of coal produces huge amount of dust. Thus the utilization of coal causes not only pollution problems but also represents a waste of resources. Finally, the mining of coal is accompanied by the emission of large amounts of methane (= coal bed methane) and this methane constitutes both a hazard to the safe production of coal (as evident from the numerous methane gas explosions that occur in Chinese coal mines) and a very potent greenhouse gas when emitted into the atmosphere (20 times more potent than CO_2) Therefore, the long-term strategy of China is to rationalize the energy mix (reduce the share of coal therein) and to apply safer and cleaner sources energy.

Whereas coal is taken as the culprit, CBM, produced concomitantly with coal and traditionally regarded as a hazardous gas during coal production, should be regarded as a kind of clean and valuable source of energy as the advancement of technology makes a more efficient utilization possible. After the successful commercial development and production of CBM through-surface drilling extraction in the United States, the development of CBM production has become an important energy strategy for countries rich in coal. CBM development in large scale through surface drilling has brought about great social and economic benefits. The reasons for this are manifold: Firstly, the main component of CBM is CH_4, which is a more potent greenhouse gas than CO_2. Therefore the reduction in CH_4-emissions will be beneficial interms of avoiding global warming. Secondly, CBM is a clean source of energy of high quality, and through CBM development and utilization, we can reduce the dependence on unclean energy such as coal and expensive oil, and rationalize the energy mix. Thirdly, surface extraction will reduce the gas content in coal beds, and as a result reduce mining tragedies during the coal production caused by gas explosions and will lead to a safer and more productive coal exploitation. Fourthly, just like natural gas, CBM utilization will help to upgrade living standards of residents and improve air quality in urban areas. Finally, the development of CBM on a large scale will also promote economic growth and create more employment opportunities.

China has abundant coal and CBM resources. CBM, regarded as an unconventional natural gas, is located in coal bed formations with a depth of less than 2000 m. The total overall reserves in China are estimated at 35 trillion m^3. In the face of these enormous quantities, the future looks bright for the development of the Chinese CBM industry. The development of CBM resources is mainly conducted through underground and/or surface extraction methods. China began to produce CBM at the beginning of 1950s, but now the purpose has changed from reducing the explosion hazard in coal production to developing a clean, safe and environmentally-friendly source of energy. CBM surface production testing began at the end of 1970s, but it didn’t achieve the expected results, because of the incorrect selection of well sites and the limitations in technology and equipment available at the time. In the 1990s, with the introduction of technology from the United States, the CBM surface development started a new phase. After carrying out exploration and development tests for more than 10 years, the surface extraction methodology has been making a gradual progress.

CBM development is controlled by resource conditions, technology, government policy, energy price and various economic factors. Though China has put substantial investments in the CBM industry, this investment is still exploratory in nature: the commercial development of the CBM industry is still in a primitive stage. But these exploration tests have laid the foundation for the technology development of CBM industry.

Against the above background and with the support from the Chinese Government, the EU-China Energy and Environment Programme launched a tender procedure for a feasibility study of CBM production in China. The tender procedure was won by China University of Petroleum Beijing. The contract was signed 25 June 2007.

Following the signing of the contract China University of Petroleum (Beijing) took full advantage of its expertise in the related subjects and organized an interdisciplinary research team comprising of 4 professors as chief researchers and about 20 other researchers. With the help of China United Coal Bed Methane Corp. Ltd. and PetroChina Research Institute of

Petroleum Exploration and Development-Langfang, the team has been working on the project for eight months, finalizing the work in March 2008.

Brief description of the final report

Chapter 1 CBM overview

This chapter mainly introduces the basic concept of CBM, formation process and mechanism, chemical components, reservoir conditions, typical classifications, development methods, waste water treatment, fundamental utilization, basic problems related to the development and the use of favourable CBM resource opportunities.

Chapter 2 World-wide CBM development

The second chapter is an overview of world-wide CBM developments and experiences,, with special reference to the experiences of the United States, Canada and Australia who are most active in developing CBM. This chapter also provides references to the Chinese CBM industry development with respect to basic infrastructure; applied technology research relating to coal reservoir and geological conditions; financial support; market creation; and regulation.

Chapter 3 CBM Resources in China

Based on a review of previous research, this chapter discusses the framework of Chinese CBM resource distribution at four levels, i.e. CBM region, CBM block, CBM belt and CBM field: This chapter provides the results of:

- collecting and analyzing many geological parameters (i.e. coal-formation era, main coal ranks, burial depth, CBM saturation, CBM concentration, resource density, CBM quantity etc.) and assessing three key parameters (i.e. resource density, CBM quantity and CBM concentration of the selected blocks) in 56 CBM belts;
- carrying out comprehensive evaluation and ranking of the CBM belts with the Weighted Mean Synthesis Evaluation Method and optimally selecting these CBM belts according to the threshold values of the resource concentration, resource abundance and resource scale;
- sorting out parameter indexes (including coal rank, burial depth, permeability, coal thickness, CBM bearing area size, CBM concentration, geological conditions, market potentiality etc.) according to geology background, reservoir, resources and conditions for development.
- making a comprehensive assessment and ranking of 85 target mines, using 4 mine prospect classifications: i.e. First Priority, Second Priority, Priority and Low Prority

The above analyses form the foundation for the economic evaluation of the technological development prospects from a resource availability point of view.

Chapter 4 The CBM Technology of China

In this chapter China’s CBM exploration and production technology is studied based on the world wide CBM technology developments, thereby linking the specifics of China’s CBM geological structures with CBM exploration technology, drilling technology, production technology and enhanced recovery technology and making an analytical assessment thereof; summarizing China’s more mature CBM exploration and development technology, and a series of technological areas that need further research. Meanwhile, on the basis of the geological block selection in the third chapter, on the technology available, and on the selection of vertical wells and horizontal wells as basic well patterns, use was made of the related software programme to predict the CBM production of the prospects with promising productivity in order to present a sound economic evaluation and comprehensive prospect selection in the following chapters.

Chapter 5 Economic Evaluation of CBM Development in China

In this chapter economic evaluation of each of the CBM blocks with promising productivity is carried out on the basis of resource evaluation, prospect ranking, and the available technology to simulate CBM production of different types of wells. The contents of this chapter include:

- analysis of marketing environment
- demand prediction for each target region
- analysis of economic factors affecting the development of the CBM prospects
- establishment of an economic evaluation system
- economic evaluation of China's main CBM blocks with promising future using the economic evaluation methods and software as developed by the China University of Petroleum;
- quantification and evaluation of social benefits of China's CBM production
- comprehensive ranking and optimization of China's CBM prospects according to the classification model developed by the University.

Chapter 6 Introduction of Favorable CBM Prospects and Pilot Test Proposals in China.

This chapter introduces the results of economic evaluation and presents suggestions for those CBM prospects with "priority" according to comprehensive classification system developed. Among those preferred prospects, based on the current exploration and development activities, market conditions, resource conditions, risk level and so on, it is suggested that the Hancheng prospect should be the next CBM testing target. In addition also basic conditions for conducting CBM pilot test in Hancheng prospect are put forward. This includes the conceptual design of pilot test in Hancheng prospect and estimation of the investment and costs of the pilot test in Hancheng prospect.

Chapter 7 The CBM Activities and Industry Development in China.

This section consists of two parts: first, a summary of the CBM exploration, development and utilization activities in China; second, some advice is provided for policy makers to accelerate the development of CBM industry, taking into account the reality of the Chinese CBM industry and difficulties in its development.

The project of "The Feasibility Study of CBM Production in China" is a very comprehensive project and the expertise of many disciplines has been involved. To the satisfaction of all the participants in this study, a great deal of research has been accomplished at relatively large scale in a relatively short time, resulting in a unique piece of work: the feasibility mapping of all of China's CBM prospects. Nevertheless, the researchers feel that the work is still not finished and that further work is still required to improve both the quality and completeness of the study. They would welcome suggestions and comments from the readers of this report.

Contents

Executive Summary

As a net oil importer since 1993, China's dependence on foreign oil supply has been rising continuously, reaching 47% in 2007. As a consequence China is no longer impervious to the dramatic changes in crude oil prices, moreover in the case of stagnant international crude oil supplies, China would also feel the pinch, with dire consequence for its economy.

The increasing dependence on international energy compel China to use energy sources other than oil, such as coal, natural gas, nuclear energy, hydropower, wind power, solar energy and coal bed methane. Besides coal, natural gas resources are most abundant but are used at a very low scale in China. Although as a clean energy source, natural gas is expected to develop substantially, just like wind power, solar energy and coal bed methane gas its share in the energy mix will be remain limited. Thus, in order to support the economic development, the abundantly available coal has remained and will be the most important source of energy in China's energy structure for the foreseeable future. China's current production amounts to more than 2 billion tons per annum.

China's coal reserves, from energy sufficiency point of view, can meet the demands of its economic development. However, the rapid development of the coal industry and the enormous coal production and utilization have caused serious social and environmental problems in view of the concomitant emissions of particulate matter, CO_2, SO_2, NO_x and other harmful gases, especially in the (low-stack) residential areas. Moreover, the emission of CO_2, a greenhouse gas, will contribute to global warming and as China has become a dominant player in this field, its contribution to global warming is not insignificant aggravated by the low efficiency of most of China' s coal burning facilities. In addition, also the production and transportation of coal produces huge amount of dust. Finally, the mining of coal is accompanied by the emission of large amounts of methane (= coal bed methane) and this methane constitutes both a hazard to the safe production of coal (as evident from the numerous methane gas explosions that occur in Chinese coal mines) and a very potent greenhouse gas when emitted into the atmosphere (20 times more potent than CO_2)

Given the above, the long-term strategy of China is to rationalize the energy mix (reduce the share of coal therein) and to apply safer and cleaner sources energy.

Whereas coal is taken as the culprit, CBM, produced concomitantly with coal and traditionally regarded as a hazardous gas during coal production, should be regarded as a kind of clean and valuable source of energy as the advancement of technology makes a more efficient utilization possible.

After the successful commercial development and production of CBM through-surface drilling extraction in the United States, the development of CBM production has become an important energy strategy for countries rich in coal. CBM development in large scale through surface drilling has brought about great social and economic benefits. The reasons for this are manifold: Firstly, the reduction in CH_4-emissions will be beneficial in terms of reducing the contribution to global warming. Secondly, through the use of CBM as a clean source of energy of high quality we can reduce the use of unclean energy such as coal and expensive oil, and rationalize the energy mix. Thirdly, through surface extraction will reduce the gas content in coal beds, and as a result reduce the number of mining tragedies during the coal production caused by gas explosions and will lead to a safer and more productive coal exploitation. Fourthly, just like natural gas, CBM utilization will help to upgrade living standards of residents and improve air quality in urban areas. Finally, the development of CBM on a large scale will increase the security of energy supply.

The total overall CBM resources located in coal bed formations with a depth of less than 2000 m in China are estimated at 35 trillion m^3. In the face of these enormous quantities, the the future looks bright for the development of the Chinese CBM industry. The development of CBM resources is mainly conducted through underground and/or surface extraction methods. China began to produce CBM at the beginning of 1950s, but now the purpose has changed from reducing the explosion hazard in coal production to developing a clean, safe and environmentally-friendly source of energy. CBM surface production testing began at the end of 1970s, but it didn't achieve the expected results, because of the incorrect selection of well sites and the limitations in technology and equipment available at the time. In the 1990s, with the introduction of technology from the United States, the CBM surface development started a new phase. After carrying out exploration and development tests for more than 10 years, the surface extraction methodology has been making a gradual progress.

CBM development is controlled by resource conditions, technology, government policy, energy price and various economic factors. Though China has put substantial investments in the CBM industry, this investment is still exploratory in nature: the commercial development of the CBM industry is still in a primitive stage. But these exploration tests have laid the foundation for the technology development of CBM industry.

Against the above background and with the support from the Chinese Government, the EU-China Energy and Environment Programme (EEP) designed a study on the Feasibility of Coal Bed Methane production in China, which was subsequently committed via a tender procedure, which was won by China University of Petroleum, Beijing. The contract was signed 25 June 2007.

Starting the work immediately following the signing of the contract, China University of Petroleum, Beijing took full advantage of its expertise in the related subjects and organized an interdisciplinary research team comprising of 4 professors as chief researchers and about 20 other researchers. With the help of China United Coal Bed Methane Corp. Ltd. and Langfang Branch of Research Institute of Petroleum Exploration and Development of PetroChina, the team has been working on the project for eight months, finalizing the work in March 2008.

Conclusions and Recommendations

1. Experiences and Lessons learned from the Development of Overseas CBM Industries

1.1. Abundant Resources are Substantial Foundation for CBM Industry Development

After the U.S. took the lead in the successful surface extraction of CBM, CBM began to be seen as a kind of valuable resource by the world. Taken as an industry, the quantity of CBM resources is the critical factor for CBM industry development, and only the rich CBM resources can support the development of large-scaled commercial development and utilization, and finally efficiently foster the CBM industry. The United States, Canada and Australia are the countries with the largest CBM resources in the world.

1.2. Growing Demand for Natural Gas Secures a Reliable Market for CBM Industry Development

Because of the similarity of the two gases, CBM and natural gas have the same markets. At present the world's oil supply is relatively tight, resulting in high oil prices. Furthermore, many countries in the world increasingly pay more attention to environmental protection, and this attention has resulted in the rapid increase in the demand for natural gas in residential areas and the power generation industry. As a result the gap between natural gas supply and natural gas demand is continuously widening. This creates a opportunities for CBM. which is the main reason to stimulate the development of coal-bed methane and promotion the CBM industry。

1.3. Developed Natural Gas Infrastructure and Open Access Policy Is an Important Condition for CBM Industry Development

Although on in small-scale developments the CBM produced is transported as pressurised gas by means of trucks, this method is inconceivable for large-scale developments, for obvious economic and practical reasons. In this respect it goes without saying that the use of existing natural pipelines is favored, if sufficient unused transportation capacity exists. Some countries, such as the United States and Canada, have well-developed natural gas storage and transportation facilities and utilization infrastructure. The presence of a developed distribution system is thereby a greatly facilitating factor that ebales the commercial production of CBM. It is thereby essential that CBM producers/transporters have open access to these transportation facilities. In the United States, after its complete reform of the natural gas market, natural gas infrastructure operators were no longer engaged in the business of gas sales. Under the supervision of the government, they provided gas producers or users with fair and reasonable gas transportation and storage services. The results of this reform allow CBM producers to distribute their coal-bed methane at much lower cost than when they would have to set up their own distribution network.

1.4. Theoretical Research and Technical Development Is Key Support for CBM Industry

CBM exploitation is a technology-intensive industry and the CBM accumulation and production processes differ from those of natural gas, and, therefore, it is essential to do research and develop suitable theories and technologies for CBM production. As for the main CBM production countries, the U.S. has already given form to advanced technologies for drilling, completion, stimulation and production as well as to fully-fledged production theories aiming at the middle-low coal rank. Thus the U.S. has become the most successful CBM production country in the world. Based on the characteristics of low density, low pressure, low permeability, Canada invented the coiled tubing drilling technology and the fracturing technique using nitrogen foam injection and learned the multi-branch horizontal well technology from the United States and thus improved the CBM production and achieved a rapid development of the coal bed methane industry. In view of the high gas content and low permeability characteristics of its coal seams, Australia developed the “short radius drilling technology” and “the close radius drilling technology” to improve the coal seam permeability, and thus increasing the CBM production. Benefitting from technical innovation, the Australian CBM industry has developed rapidly.

1.5. Encouraging Policies Are Driving Forces for CBM Industry Development

Compared with that of conventional natural gas, the CBM industry has its unique characteristics, such as low individual well production, long production cycle, high initial investment and high investment risks, and therefore, in the early development of the CBM industry, it is unable to compete with conventional natural gas. In order to encourage enterprises to invest in the coal-bed methane industry, the government needs to implement encouraging policies to increase profits and reduce risks. Encouraging policies include financial support for the research in the basic theory and critical technology as well as exploration work, tax relief, direct financial subsidies, etc. The support for theoretical and technological study can contribute to the CBM development theory and technologies suitable for the specific geological features in order to increase production and reduce costs. The fiscal support for the CBM development can increase the CBM market competitiveness, and improve economic feasibility of the CBM development projects. These encouraging policies play an important role in attracting investments in the CBM industry.

1.6. Rational Laws and Regulations Are Basic Factors for CBM Industry Development

CBM and coal have the characteristic of co-existence, and therefore conflicts may arise when the licenses for both are issued: this requires effective co-ordination. In addition, just like the natural gas industry, the CBM industry also face issues such as mineral rights, exploration, development, pipeline transportation, distribution, infrastructure construction, environmental protection, and so on. Only through legislation it can ensure that the stakeholders in the CBM industry become clearly aware of their rights and obligations and can an effective system of regulation on the CBM industry and the protection of legitimate rights be realized. The main CBM production countries regulate the exploration and development of CBM and implement encouraging polices by promulgation laws and regulations. All laws and regulations appear to be implemented with good results.

1.7. Increasingly Stringent Environmental Requirements Are Driving Force for CBM Industry Development

The main component of CBM is CH_4, which is a greenhouse gas. The greenhouse effect of CH_4 is about 20 times that of CO_2. The "*United Nations Framework Convention on Climate Change*" adopted on 9 May 1992 in New York, states that the developed countries assume the responsibility and obligations of reducing greenhouse gas emissions. The direct emission of the methane into the air from coal mining is one of major sources of methane emissions and all CBM production countries including developed countries put forward strict requirements for CBM emission. The "*<United Nations Framework Convention on Climate Change> Kyoto Protocol*" adopted in Kyoto Japan in 11 December 1997 further defines the emission reduction obligations of the developed countries. This reinforced the interest of the major CBM production countries in CBM production and utilization.

2. China CBM Resources

2. 1. Resources Conditions and Geological Features

CBM Resources

According to the resources evaluation, the CBM resources with buried depth of less than 2000 m are distributed mainly in the north and northwest of China. The geological resources in the northern, northwestern, southern and northeastern regions account respectively for 56.3%, 28.1%, 14.3%, and 1.3% of the total national CBM resources. The CBM resources with buried depth of less than 1000 m, of 1000 m ~ 1500 m and of 1500 m ~ 2000 m account respectively for 38.8%, 28.8% and 32.4% of the total amount. About 90% of the total amounts of CBM resources are distributed in the early Jurassic, Carboniferous and Permian coal seams, with the most (46.1%) in the early Jurassic coal seams and the second most (43.5%) in Carboniferous-Permian coal seams.

CBM Basins

There are many large basins with more than 1 trillion m^3 CBM resources: they include East Ordos Basin, Qinshui Basin, Zhuiger Basin, Yunnaeast-Guizhouwest Basins, Erlian Basin, Tuha Basin, Talimu Basin, Tianshan mountain Basins and Hailaer Basin. The recoverable resources in East Ordos Basin and in Qinshui Basin are more than 1 trillion m^3. The largest CBM fields in China include Ordos Basin in Shanxi and Inner Mongolia, Qinshui Basin in Shanxi, Tuha in Xinjiang and Liupanshui in Guizhou.

Geological Structures

The Geological structures of coal fields are complex. Some coal basins are strongly deformed in the later periods, forming diverse tectonic structures. The geological accumulation conditions of coal seams and CBM resources are relatively simple in large and middle large basins such as Ordos basin, but relatively complex in middle and small basins. Favourable CBM fields were found in middle-rank coal areas in China, such as Daning basin, just like in various other countries. However, contrary to world expert’s expectations, favourable CBM fields were also found in high-rank-coal areas, such as Qinshui basin. (This is the world’s first high rank coal CBM field). This feasibility study suggests that research is needed to understand, how it is possible that these unlikely deposits would yield favourable CBM fields.

CBM Content

The most coal seams in China are rich in CBM. According to the investigation into 105 coal fields in China, there are 43 coal fields with average CBM contents of more than 10 m^3/t, which account for 41% of the total national resources. There are 29 coal fields with average CBM contents of 8 m^3/t ~ 10 m^3/t, accounting for 28% of the total. There are 19 coal fields with average CBM contents of 6 m^3/t ~ 8 m^3/t, accounting for 18% of the total. There are 14 coal fields with average CBM contents of 4 m^3/t ~ 6 m^3/t, accounting for 13% of the total. The CBM concentration degree is relatively high: generally more than 4 m^3 CBM /per m^3 coal. The average CBM content of all the CBM fields in China is estimated at about 0.115 billion m^3/km^2.

Reservoir Pressure

The coal reservoirs in China are predominantly under-pressure reservoirs, only a few have high pressure. The lowest reservoir pressure gradient is 2.24 KPa/m, and the highest up to 17.3 KPa/m.

Permeability

The permeability of the coal seams in China is relatively low, with values ranging from 0.002×10^{-3} μm^2 to 16.17×10^{-3} μm^2, distributed as follows: 35% of the coal seams have permeability of less than 0.10×10^{-3} μm^2; 37% have permeabilities ranging from 0.1×10^{-3} μm^2 to 1.0×10^{-3} μm^2; and 28% have permeabilities of more than 1.0×10^{-3} μm^2; only few coal seams have permeabilities of more than 10×10^{-3} μm^2.

2.2. CBM Resources Distribution Regionalization in China and the Favorable CBM Development Areas

In accordance with the classification methodology used by PetroChina and China CBM the CBM deposits in China are divided into zones, regions, belts and prospects. Altogether there are 4 CBM zones, 10 CBM regions, 56 CBM belts and over 100 CBM prospects in the whole country.

Three parameters, namely the CBM resources amount (total amount in the belt), CBM resource density (amount of CBM per km^2) and CBM content (amount of CBM per tonne of coal), are selected as the basis for ranking of CBM belts in terms of an index. According to this ranking analysis, the top 20 most favourable CBM belts are Qinshui, North Ordos Basin, Huoxi, Liupanshui, Tuha, Zuo-He, Ordos Basin East Edge, Henan East, Taihangshan East Foot, Weibei, Henan West, Yili, Hebei Central Plain, Daning, Hunan Sourth, Anhui Sourth, Beijing-Tangshan, South-Sichuan-North Guizhou, Middle Hunan.

For ranking of CBM prospects, the following specific parameters were chosen and combined in an index: the coal rank, buried depth, permeability, thickness, CBM-bearing area, CBM content, ground conditions and market demand. This comprehensive analysis was done for 85 prospects. The top 30 most favourable CBM prospects thus found are: Sanjiaobei, Zhuluoxi, Hancheng, Lu-an, Daqingshan, Zhongliangshan, Jincheng, Xiangning, Liupanshui, Wubao, Shizuishan, Tianfu, Songzao, Gufushan, Liujiang, Heshun-Zuoquan, Xinglong, Feicheng, Xuanxia, Tiefa, Jiaozuo, Liulin, Nantong, Yangquan, Hulusitai, Hongyang, Zuozishan, Ningwu, Fugu, Xuanwu.

3. China CBM Technology

China CBM exploration and production technology was developed on the basis of conventional oil and gas technology and on foreign experiences. A brief description of the technology in use is given below.

Geophysical Technology

The geophysical technology includes seismic technology and logging technology, which is just using the conventional technology as used in the oil and gas industry.

Drilling Technology

When classified in terms of well types, the drilling technology for CBM production comprises of vertical well (including cluster well) drilling technology and multi-branched horizontal well drilling technology. When classified in terms of drilling methodology, we can identify three types: the free water drilling technique; the low solid (or “clay free”) drilling technique and the air drilling technique. The multi-branch horizontal CBM well provides the potential of high single well production and is very suitable for CBM development in low-permeability regions and for high-efficiency CBM development. However, because of the poor economic return resulting from low CBM utilization in relation to the very high investment required for the drilling of horizontal wells, currently vertical well drilling is still the dominant type of drilling in the Chinese CBM development. Currently oine of the most promising technologies for the Chinese CBM development is the so-called under-balanced drilling technique. This is a negative pressure well drilling technique, featuring fast mechanical drilling speeds and low costs, minimizing the damage to the production layer usually caused by the invasion of external liquids, thereby reducing reservoir damage and thus protecting the reservoir.

Coring Technology

To investigate the properties of the coal seams, various coring technologies are used, such as: conventional coring, sidewall coring, wire line coring and pressure coring. At present, wire line coring is the most popular coring method sued in China.

Completion Technology

To make the wells ready for production, three types of completion technology are used in the CBM development: barefoot completion, casing completion and barefoot cave completion. These technologies are explained in detail in the full text of the report. The most commonly used completion technology is that of the casing completion.

Well Cementing Technology

There are three kinds of well cementing technology in CBM development: well cementation technology with voidal micro-particle and low-density cement, cementing technology with controlled cement top and multi-staged injection cementing technology. Among them, the first technology and low-density mud cementing technology are the most commonly used in China.

Production Technology

Commonly used production technology includes rod pump, screw pump and ESP (electric submersible pump) and so on. Furthermore, the waste water from the CBM production is treated in accordance with the standards for petroleum industry.

Stimulation Technology

The production of CBM is stimulated by a number of technologies, including hydraulic fracturing technology (using water), gas injection technology using CO_2 or N_2. The hydraulic fracturing technology is widely used in China. The technology for production enhancement by gas injection is still being tested and not widely used in China.

4. CBM Economic Evaluation

4.1. China CBM Has Great Market Potential

Fast increase of the demand for natural gas provides great market opportunity for the CBM industry. Based on predictions, the demand for natural gas will continue to increase rapidly in the future in China. It is estimated that the annual demand for natural gas will reach 100 billion m^3 in the year 2010. The production will be about 92 billion m^3, and the difference of 8 billion m^3 between demand and supply will be met by imports. In 2020, the demand will increase to 200 billion m^3 and it is envisaged that about 50% of the demand will be met by gas importation. It goes without saying that if CBM could developed in a big way, the imports of natural gas could be reduced proportionally.

China's CBM resources enjoy a geographic advantage in that they are found in the middle of China, close to the market, which is different from most of the natural gas resources, which are found in remote areas. This and the social benefits resulting from its development would make CBM an important supplement of natural gas. CBM is fatalistically produced together with coal and therefore China must make the choice "to use it, or to lose it" to the atmosphere, with dire consequence in regard of coal mining safety and greenhouse gas emission if it decided "not to use it". In as much as CBM can be used to replace coal, it would also have another advantage, in that it would reduce pollution caused by the burning of the coal it replaces and reducing the current strain on coal transportation. From the above it is clear that the development of coal and CBM go hand in hand, whereby the production of CBM would make mining in the same coal deposits safer and more productive.

4.2. Economic Evaluation and Selection of Chinese CBM Prospects

The potential values of CBM resources can only be realized under suitable technical and economic conditions. The production of CBM is a complex input/output process, of which the economic conditions are influenced by a number of factors, which include: geology, geography, resource condition, the technological process used and the overall economic situation. In this research, the economic feasibility has been determined in terms of Net present Value (NPV) whereby the factors mentioned above would influence the cash flow of the CBM development.

This study has produced a ranking and optimum slection of the CBM prospects in China on the basis of the estimated economic and social benefits

The outcome of the ranking is shown below (Table E-1), whereby the criteria for selection of the favorable CBM prospects, are divided into 6 different classes (A through F) under the present industry policy.

By providing an extra subsidy of 0.01 USD per m^3 of CBM, the following prospects would enter into the A-classification: Zhina and Liupanshui (currently class C) and others would enter into B-classification: Fengfeng (currently class C), Hongmao (currently class D).

5. Selection of a site for a CBM Pilot Test

A requirement of this study was to identify areas where a pilot test on CBM (drilling and or production) would be warranted to confirm the assessments by study only. Following further study is was decided to only consider a pilot test for CBM production (not for testing drilling techniques)

In selecting a pilot test site in a favorable prospect, the following criteria have been adhered to: a) no pilot CBM production test has been carried out so far on this site; b) this favorable site has already carried out CBM exploration and evaluation activities and have proved up the CBM reserves and; c) the site has a potential market. Following these three criteria it appeared that the Hancheng prospect would be the most favorable site for the execution of a CBM pilot test. The completion of a successful test at this site would encourage and accelerate CBM development and utilization in this area.

Hancheng prospect is one of the areas where CBM exploration activites started already in the 1980s and many enterprises and research institutions have been carrying out exploration and evaluation activities in this area. A lot of preparatory work has been carried out already, determining geological and coal reservoir characteristics enabling the proving up of some of the CBM reserves. In addition, the market conditions in the Hancheng prospect are very good and completely meet the need of small-scale CBM sale. The preparatory work and the favorable market condition provide a stable base for carrying out a CBM pilot production test in the Hancheng prospect.

Table E-1 Optimal Selection Outcome of the Chinese CBM prospects

Grading	Development Decisions	CBM prospects
A	Development with top priority	Yanquan, Jincheng, Heshun-Zuoquan, Lu'an, Huodong, Dacheng, Huainan, Hancheng
B	Development with priority	Huaibei, Jiyu, Ningwu, Jiaozuo, Lianshao, Huozhou, Taiyuanxishan, Xuanxia, Fengcheng, Jixi, Tiefa, Fuxin, Hongyang, Hegang, Xinglong, Shuangyashan, Baiyanghe, Liujiang, Enhong, Daqingshan, Anyang-Hebi, Lingshan, Kailuan, Lincheng, Huhehu Depression, Boli
C	Development possible after technical research	Fengfeng, Zhina, Liupanshui
D	Economic margin	Hongmao, Fugu, Guyang, Sanjiaobei,Liulin
E	Development impossible for the time being	Ruijigou, Zhuozishan, Hulusitai, Shizuishan, Leping, Aiweiergou, Luocheng, Tianfu, Guishan, Libixia, Heshan, Tongchuan, Xiangning, Songzao, Huolinhe, Qianxibei
F	Further research required for decision	Jura, Xuanwu and Xingyi

6. Suggestions for Chinese CBM Policies and Laws

6.1. Government Supported Investment

Scientific Research Investment

The Chinese reservoir conditions are complex, which makes the exploitation rather difficult wspecially in the face of insufficient technological support in terms of CBM extraction and utilisation. There are still many critical theoretical and technical problems. Some fundamental and theoretical research also needs further strengthening, including the research into CBM existence forms and heterogeity, rules for reservoir formation and gas control factors for CBM regions with high permeability and high CBM concentrations as well as into the process of mining coal after CBM production, etc. In addition to the integration of fundamental research and technology, in order to lay the foundation for the Chinese CBM medium and long-term development of science and technology, we attention should be focussed on other leading-edge technology research, such as: the use of geophysical methods to evaluate the gas content of coal beds; post fracture response evaluation of CBM wells and fracture monitoring technology. Other research areas include: CBM enhanced recovery technology; deep coal seam exploitation technology; technology for the simultaneous production of natural gas and CBM conventional natural gas and CBM; the CBM production efficiency improvement technology and; high value-added CBM processing and utilization technology. The state should utilize the Major National Fundamental Research Program, the National Five-year Program for Tackling Key Problems, Natural Science Fund for Key Project Plan to preferentially arrange the fundamental theoretical research on CBM in order to identify the key scientific issues that constrain the development of the Chinese CBM and to accelerate the formation and development of the Chinese CBM industry.

Positive effects of a pilot test

It goes without saying that Government support for a pilot test in the best and most representative test site would be very valuable and to the benefit of large scale developments. At present, the main pilot test areas getting support from the government are located at Qinshui basin. But what is required is a pilot test for the very large Ordos basin, which has a large market potential and gelological conditions that are different from Qinshui basin. Therefore a test in Ordos basin would be more meaningful. In this way, the Government would help to increase the investment in favorable areas with perfect geological and market conditions leading to a rapid increase in production and the promotion of large-scale development of the local CBM industry.

6.2. Completion of CBM Laws and Regulations

CBM is a new kind of mineral product; its geological formation conditions and development history are different from those of coal, petroleum and natural gas, but it is absorbed on the coal as its geological carrier and it shares the pipelines and end-users with the natural gas, and, therefore, there exists a special relationship between CBM, coal and natural gas. For this reason, from the prospect of an industry development, the exploration and production of CBM needs a special, harmonious policy environment.

At present, the management of CBM resources exploration, development, production, transportation and sales in China is mainly conducted in accordance with the regulations of the State Council and Government ministries, most of which constitute rules for a single aspect of the CBM industry. There are many legal blanks. Along with the development of CBM industry, the gaps where there is no law or regulation are bound to become visible. Because of the intimate relationship between CBM and natural gas, the government should promulgate a law in respect of CBM and natural gas, which should include the whole industry chain, so as to foster the good development of CBM industry.

Moreover, it is also necessary for the State to set up strict laws and regulations, establish methane emission reduction funds, promulgate a policy for methane emission reductions and establish a penalty system using emission standards, so as to encourage companies to develop and utilize CBM.

6.3. Implementation of CBM Encouraging Policies

The CBM industry should first aim at achieving the two social objectives: i.e. environment protection and mine safety. The economic benefits should be secondary. However, the CBM development and utilization enterprises as market-oriented economic entities must be profitable, otherwise, from an economic point of view, development and utilization of CBM is not feasible. The government therefore needs to set up encouraging policies at the early stage of CBM development to balance the requirements for social benefits enjoyed by whole society and for the economic benefits enjoyed by the enterprise. Government support is necessary to overcome the difficulties relating to: unmatured theory, technology and equipment; the lack of large-scale developments and immature CBM markets.

Financing

The CBM industry development must have a reliable financing backing. In addition to direct investment, it is necessary for the government to support the CBM enterprises in obtaining financing through domestic and foreign channels. Currently, the most feasible financing channels include domestic loans, specific project financing and foreign investment.

Domestic bank loans are low-cost, fast-cycle and flexible sources of financing, but compared with mature industry projects, the CBM projects have no advantage in obtaining those bank loans. With the intensification of the banking reform, commercial banks are more and more restrictive in offering subsidized loans. Therefore, the state needs to provide more support to policy-oriented banks for the CBM industry.

Project financing is very popular internationally, and also the Chinese oil and gas enterprises often adopt this method. The projects that need project financing are usually very large-scale projects of which the financing is established by co-operation between of a number of investors, including the government, domestic and foreign banks, and investment companies. For the key CBM projects in the favorable areas, the State and local Governments should actively coordinate the establishment of cooperation mechanisms for the various relevant companies, and help them to lower project cost, and guide them to focus on bundling their forces in the completion of the project.

China's huge CBM resource and market potential are the essential bases for attracting foreign entities to invest in China's CBM industry. However, the project economics need to be improved. In this respect the State Government should support those potential CBM areas in which foreign investors would be interested. Ways to do this, would include: introduction of preferential tax policies; provision of a good infrastructure, whilst encouraginging the construction of a gas pipeline network, gas storage facilities and the establishment of gas utilising industries. In addition, such supportive measures should also include lowering the entry threshold for participants, broadening the scope of cooperation (such as with coal mine methane extraction) , encouraging foreign partners to use new technology (such as horizontal and directional wells drilling technology.), reducing the costs for contract signing, establishing supervisory mechanisms for foreign cooperation, improving and strictly implementing a relinquishment mechanism and mechanism for the timely.termination of contracts of investors that invest insufficiently

Tax and Subsidy

The key reason for the success of the United States CBM industry policies is that it is established in accordance with the conventional gas policies, but more favorable, and this has promoted the formation and fast development of the CBM industry. Presently, China learns from the foreign experiences and makes some economical preferred policies. Judging from the results of the economic evaluations, tax reduction could greatly improve the economic benefits. Moreover, the amount of tax cuts required for the CBM development is very limited.

The provision of subsidies is the most effective tool for Governments to regulate and control the development of CBM. In this respect we advocate that the Government applies a subsidy policy for the development of the CBM industry, whereby the geological and geographical conditions of the areas are taken into consideration, resulting in a differential subsidy policy.

In terms of greenhouse gas emission, coal mine production safety and security of energy supply, the social benefits derived from the production of 1 m^3 CBM can be expressed as equal to 0.035 USD. Thus we suggest that the Government, provides a subsidy of 0.035 USD per cubic metre of CBM to Fengfeng, Liupanshui, Zhina and other CBM prospects (but not for power generation), to improve the development of CBM resources in these prospects.

CBM Price

From foreign experiences it is known that a favourable price policy has a great positive effect on the development of the gas industry. In China, lots of citizens still enjoy fiscal subsidies, and the price of gas extracted in the coal mine area provided to workers as welfare is low, but this, of course, is undesirable from the viewpoint of developing a CBM industry. The country needs to set a reasonable gas price policy and the relevant departments of local governments should loose the control of the price of gas as soon as possible. This will ensure the competitiveness of CBM vis-à-vis natural gas, town gas and LNG, and will create a favorable environment for the CBM industry.

Arrangement of Purchasing Emission Reduction Quota of Greenhouse Gases

The Clean Development Mechanism is a mechanism to execute the arrangements stated by the Kyoto Protocol for developed countries to realize emission reductions outside their own borders. The crux of this mechanism is to allow developed and developing countries to trade in reduction emissions {in the form of Certified Emission Reductions (CERs)) on the basis of investment projects. The development and utilization of CBM will result in a substantial reduction in greenhouse gas emissions and therefore CBM is a most important important area for the implemention of the CDM mechanism. In this respect the State should promote the publicity concerning this mechanism, so as to provide more opportunities to obtain the necessary funds and technology.

6.4. Enhancing Construction of Natural Gas (CBM) Basic Pipe Network, and Implementing the Licensed Access to Pipe Network

Enhancing Construction of Natural Gas (CBM) Basic Pipe Network

The prediction of market demand around CBM prospects shows that the local CBM demand is not sufficient for large-scale commercial developments. Hence transporting CBM to other markets by pipeline is virtually the only way to solve this problem. With the economiu benefits of CDM being as low as they are, adding the construction of long distance pipelines would reduce the profitability still further, discouraging companies to invest. However, CBM and natural gas could be transported and utilized simultaneously, and have a common market. So, when planning the construction of natural gas long-distance pipelines, the State should fully consider of the possibility of joint transportation and distribution of CBM and natural gas resources, could possibly arrange for the natural gas long-distance pipelines to run close to the CBM production bases; require the natural gas pipelines to have sufficient capacity to also allow for future CBM production and transportation, in order to lower the transportation costs for the CBM industry. In this respect it goes without saying that the construction of long-distance CBM pipelines should be included in national infrastructure planning, and that periodically, investments should be made in infrastructure funds in the area to gradually set up a CBM (natural gas) long-distance pipeline network in China.

Implementing Admittance Regime of Pipe Network

For the development of the CBM industry it will be necessary to ensure that all potential CBM producers would have access to existing (natural gas or CBM) pipelines, covered under the principle of Third Party Access. In this we assume that: pipeline companies would be independent legal entities, who have well-developed markets and have excess capacity for the transportation of CBM. In that case we postulate that there would enough CBM suppliers willing to use this service instead of constructing the pipelines themselves. However, China does not (yet) have the right legal condition in place, so it would be difficult to impose the principle of third party access at this moment. Along with the development of CBM and natural gas industries, there will be more and more suppliers who need the pipeline to sell their CBM (natural gas). So, as a transitional measure, negotiated third-party access system should be considered. Pipeline companies and shippers together determine access. What the government needs to do is to require transportation traders to publish the tariffs of their pipeline transportation and related services. The fully fledged third-party access system could be implemented later.

Chapter 1 Coal Bed Methane Overview

As a kind of unconventional natural gas resources, coal bed methane (abbr. to CBM) and natural gas have the same usages but different basic properties. Governments of each nation takes the CBM industry as a sector to contribute to energy security, environmental protection and coal mine production safety, and thus the development of the CBM industry in China is at an important historical opportunity. In this chapter, the above contents will be given a brief introduction.

1.1. Definition and Basic Characteristics of CBM

From the mineral resource point of view, CBM is unconventional natural gas, with methane as the main component, and is generated in the process of coalification, accumulated in coal seams and their adjacent rock formations, and can be extracted from coal seams.

To CBM, coal seam is not only gas source rock, but also reservoir rock. The coal seam has a series of special physical, chemical and special rock mechanical properties. As a result, CBM is obvious differentiated from conventional natural gas (See Table 1.1) in the aspects of adsorbent mechanism, porosity and permeability property, gas-producing mechanism of gas wells, and dynamic production, with typical characteristics.

1.2. CBM Generation

1.2.1. Types and Mechanism of CBM Generation

Gas generates across the whole course from peat to the different ranks of coal. According to the different generation mechanisms, CBM can be classified as biogenic gas and thermal gas. Biogenic gases generate in the immature stage of anthragenesis, and thermal gases generate in the mature and over-mature stage of anthragenesis [1~3].

1.2.1.1. Biogenic Gas

Biogenic gas is mainly composed by CH_4, and it is generated by the degradation of organic material caused by series of complex active processes of microbe. According to the different generation stages, biogenic gas can be divided into protistic gas and secondary biogas.

1) Protistic gas

Protistic gas is generated through the decomposition of organic materials, and it is mainly composed of CH4.The specific conditions are: the beginning of anthragenesis (R_0<0.5%), low temperature (<50 ^{0}C), shallow burial depth and the affection of bacterium. There are two specific means of the generation of protistic gas: one is the reduction of $CO_{2,}$ and the other is fermentation of methyl materials (generally acetic acid) .The main conditions for the generation of biogenic gas are: anaerobic environment; low sulphate concentration; low temperature; sufficient organic material; high PH value; sufficient space.

2) Secondary biogas

Rice (1981) and Scott (1944) believe that in the near geologic epoch, the coal beds are uplifted, active groundwater system, air and fresh water form the beneficial environment for the activities of microbe. In the relative lower temperature, the wet gas, CH_4 and other organic compounds are catabolized by micro, so the secondary biogas generates (mainly CO_2 and CH_4).The geochemical components of secondary biogas are similar to protistic gas, and the main difference lies in the thermal evolution stage of the coal. In the generation stage of secondary biogas, the range of R_0 is broader, generally between 0.30%~1.50%, and the coal beds are uplifted to a shallower part. The generation and storage conditions of secondary biogas are as follows: coal beds buried and carbonized to the brown coal or higher rank; regional uplift; suitable penetrability; flowing water recharging to the coal beds at the border of the basin; bacterium migration to the coal beds; high reservoir pressure and good trap condition.

1.2.1.2 Thermogenic Gas

With further metamorphism, coal beds evolve from low rank to high rank and when it develops into kennel coal (R_0<0.50%), the thermogenic stages start. With further anthragenesis, C_2 and water are exhausted and CBM builds up until the anthracite II and III stages (R_0<6.00%) begin.

At the different generation stages, thermogenic gas is divided into thermal degradation gas and thermal pyrolysis gas.

1) Thermal degradation gas

Thermal degradation mainly happens in the kennel coal to lean coal stage of anthragenesis (0.5%< R_0<1.9%). With the heat power (<250 ^{0}C), a great quantity of hydrocarbon components are generated at this stage, with mainly gas and also some oil as subsidiary generated. The component of gaseous hydrocarbon is mainly CH_4; the content of heavy hydrocarbon is increasing gradually.

Table 1.1 Difference between CBM reservoir and conventional natural gas

Characteristic	CBM	Conventional natural gas
Reservoir type	Layered katogene rock	Local trap
Gas source	Self-generation	Allogenic
Reservoir lithology	Combustible organic rock of high enrichment organic material, easily subjected to the injury of the well liquid, cement etc	Almost 100% dead matter rock, not easily damaged
Double porosity composition	Hole in the coal matrix block is the main hole, accounting for most of the total hole volume; Crake system is natural gas hole, accounting for the second part, basically equally spaced distribution makes coal discontinuous	Mainly generating in limestone, dolomite, shale and tight sand. Intrinsic fracture (including joint, crake, dissolve path, hole and so on) divides hole among grain into diamonds, and is in random distribution
Storage of gas	Most of the gas is absorbed at the inner surface of coal. There is few or none free gas in hole space	Gas is stored in hole space of stock at the condition of dissociation
Flow mechanism	Concentration gradient causing pervasion, then percolating in crack because of gradient of pressure, this is the flow in basic quality	Gradient of pressure arouses laminar flow, which obeys Darcy law; Turbulent flow may appear in immediate vicinity of wellbore
Gas-output mechanism	Desorption-diffuse-infiltration fluid	Flow because of the gradient of pressure of gas itself
Production condition of gas wells	Gas output will increase with time till to the max, and then decline greatly. Water emerges at first, gas and water value increases with time	Gas output reaches the max at first, and then declines with time. Few or none water comes out, but gas and water value declines with time
Mechanical property	Because of the brittleness and developed crack, coal is a kind of weak rock. This makes the bad stability of drilling, and affects the effect of hydraulic cracking. Under certain condition, special cavity well completion methods may be adopted. Stretch modulus is within 700MPa	Solid rock makes the good stability of drilling. Stretch modulus is within 700MPa
Reservoir nature	Easy to be compressed. Pore volume compacting factor is within 0.01 MPa^{-1} and porosity and permeability stress is sensitive, which changes apparently during production period	Small compressibility, pore volume compacting factor within 10^{-4} MPa^{-1}, porosity and permeability keep stable in general

Resource: Zhang Xinmin, 2002.

2) Thermal pyrolysis gas

Thermal pyrolysis mainly happens in the lean coal to anthracite coal stage of anthragenesis (R_0>1.9%). Under the high temperature, the remaining Kerogen, liquid hydrocarbon and partial heavy hydrocarbon pyrolyze and generate gases. The gas at this stage is mainly CH_4, and it is dry gas with low heavy hydrocarbon.

1.2.2. CBM Components and the Influencing Factors

1.2.2.1. Components of CBM

The main component of CBM is CH_4, and it also contains C_2H_6, C_3H_8, C_4H_{10} and part of CO, CO_2, N_2, H_2, and H_2S. According to the statistics of 1380 production wells in The United Statesn presented by Scott in 1995, the basic components of CBM are 93% of CH_4, 3% of CO_2 [3].

1.2.2.2 The Factors Affecting CBM Components

Though the main component of CBM is CH4, the component can be of great difference with CBM in different basins, of different ranks and from different CBM wells. The difference occurs because the generation of CBM is the result of long term anthragenesis. Within the long time of generation and in the complex and particular generation environment, the component will be affected by many factors. The critical factors affecting CBM components are as follows: maceral of coal; types of CBM; desorption-diffusion-migration of CBM; reservoir pressure; coal rank; hydrologic and geological conditions.

1.3. CBM Reservoir and Its Formation Conditions

1.3.1. Definition of CBM Reservoir

CBM reservoir is coal body of separate structural attitude, which conserves gas of certain amount and locates in the same coal-bearing strata in the formational pressure (water pressure and gas pressure). It forms in the process of coal seam thermal evolution affection, evades from entire damage in later tectonic movement and outputs in layers. CBM is the basic geologic unit for CBM exploration and exploitation [1~3].

The characteristics of self-generation, self-reservation, mainly being in adsorption form and not following gravitational differentiation, differentiate CBM reservoir from conventional oil-gas reservoir. As to conventional gas reservoir, oil, gas and water continuously differentiates in the process of migration and accumulation, so whatever traps or form it is in, it typically accumulates in low gas bearing space which locates at higher place of a reservoir and is formed because high gas potential surface closes. CBM is beyond the control of the trap which is 3-dimensionally-closed low gas potential composed of high gas potential surface. With good cap conditions and reasonable formation pressure, which could adsorb certain gas, gas reservoir would form at either high or low parts of the reservoir (coal seam).

1.3.2. Formation Conditions of CBM Reservoir

Formation conditions of CBM reservoir include condition of accumulation and reservation. Accumulation condition is affected mainly by coal seam thickness and coal metamorphic grade, while reservation condition is affected mainly by cap and geologic feature. Moreover, because burial depth of coal greatly affects gas component, reservoir pressure and permeability of coal seam, it is also one important factor affecting CBM reservoir [2].

1) Thickness of coal seam

Coal seam of certain thickness is the foundation of forming CBM reservoir. The thicker the coal seam is, the better it is to CBM reservoir.

2) Coal metamorphic grade

Coal metamorphic grade controls the ability to generate gas and reserve gas of coal seam, so it is very important for the formation of CBM reservoir, which is exemplified by the following two aspects:

a. Too low coal metamorphic grade is not favorable to the formation of CBM reservoir. As for brown coal, since it is at the biochemistry gas generation stage, the gas content of coal seam is not high when pyrolytic gas is going to generate. Meanwhile, aeration ability of brown coal seam is very good, which causes easy effusion of CBM. Thus it is hard for brown coal to generate CBM. But, when the burial depth and thickness of coal seam is sufficient and there is a good cap, it is also possible to form CBM reservoir in brown coal.

b. When coal metamorphic grade is too high and coal seam loses its reserving ability, CBM reservoir can not generate. Meta-anthracite of superelevation metamorphic has very low porosity and restricted reserving ability, it could not generate CBM reservoir.

3) Burial depth of coal seam

Burial depth of coal seam is the main factor of pressure. Pressure increases with more burial depth, and adsorption ability of coal seam to methane also rises with it. The concrete representation is that gas content of coal seam regularly increases with additional burial depth. Moreover, if geologic feature changes, which moves coal seam up and down, the pressure will be changed, and then reservation of CBM reservoir will be impacted.

4) Closure condition

To CBM reservoir, gas mainly presents in adsorption form, and reservoir pressure is very low. Therefore its demand for closure is not as strict as natural gas reservoir. However, good closure condition is also important for the formation of CBM reservoir, because it divides different coal measure strata into separate systems, to make sure that hydrocarbons gas adsorbing in coal seam could reserve in coal seam in the adsorption form for long, and to decrease the emission of dissolved gas and free gas.

5) Hydrogeological conditions

Closed hydrodynamic system and the high pressure caused by hydrodynamic restrain is the favorable condition for CBM adsorption and accumulation. If closed hydrodynamic system is damaged, the pressure balance of coal seam will be disturbed. Thus, adsorbing gas will decrease, and dissolved gas and free gas will emit.

1.3.3. Types of CBM Reservoirs

So far, no classification of coalbed methane reservoir is commonly accepted. The more reasonable classifications are the eight kinds (see Table 1.2) put forward by Wang Hongyan [2] and the four types by Diaoqiangbei (see 3.3.1)

Table 1.2 Type, characteristic and example of common CBM reservoirs

Type	Characteristic	Example
Hydraulic pressure monoclinic CBM reservoir	Locating in edge of big depositional basin, stable structure, nonbudding fault, distribution is stable and fargoing, burial depth < 2,000 m	Ordos Basin, Qinshui Basin
Hydraulic pressure syncline CBM reservoir	Locating in old middle-small coal basin, max burial depth < 2,500 m, the distribution is stable and fargoing, nonbudding fault and structure	San Juan basin (U.S.) Pingdingshan Syncline Coal Basin
Air pressure syncline CBM reservoir	Locating in new middle-small depositional basin, burial depth < 4,500 m, excess pressure, stable structure, nonbudding fault, stable and fargoing distribution, hyposmosis, low production	Kaiping syncline
Fault-block CBM reservoir	Locating in middle-small coal basin, burial depth < 2,000 m, development fault, active structure, simple hydrologic geology	Lianghuai, Weibei, Yuxi
Anticline CBM reservoir	Locating in middle-small coal basin, middling structure and fault, simple hydrologic geology	Hunan Baisha Coal Field
Layer-lithology CBM reservoir	Locating in middle-small coal basin, limnic basin is most developed, small and unbalance distribution, burial depth < 2,000 m	Zhungeer, Tuha
Rock mass piercement CBM reservoir	In coal basins with invasive magma, middle complex structure, developed fault	Tiefa Coal Field
Complex abundant area	In many types of coal basins	

Source: Wang Hongyan etc, 2005.

1.4. CBM Development and Utilization

1.4.1. CBM Development

1.4.1.1. CBM Development Mode

There are two common modes of CBM development: underground gas extraction and surface drilling extraction.

1) Underground gas extraction

Underground gas extraction is that a hole is drilled in the coal mine tunnel, and then CBM can be extracted by a CBM pump on the ground. Under this development mode, the CBM production is low, the methane concentration is not high (20%~50%), and it is often affected by mine development. The main purpose of this development model is to insure the coal mine safety and the utilization efficiency of the CBM is comparatively low.

2) Surface CBM drilling extraction

Surface CBM drilling extraction is that the wells are drilled from the ground to the coal seams, and then the CBM in the coal seams is desorbed by water drainage, depression and flow to the ground through the wells. Under this development model, the CBM production is higher, the production life is long, and the methane concentration is high (more than 90%). For these reasons, the method can support large-scaled commercial utilization. Based on this development model, the CBM can be extracted through the wells from the coal seams to the ground and utilized like the natural gas, and then it began to be regarded as a kind of mineral product and listed in the mineral resources with significant economic value. To guarantee the high CBM recovery and obtain sufficient economic benefits, this development model has strict requirements for CBM resources, geological structure of coal bed, gas content, permeability and geographical environment.

1.4.1.2. The Characteristics of CBM Production

CBM exists in coal seams in three states: free state, adsorption state and dissolved state, in which adsorption state accounts for the dominant state. To obtain industrial production, first methane must be desorbed from the coal surface, and then diffused through the coal matrix and micro-porosity, and finally seeps to the bottom through the cracks and cleat. This makes the CBM output experience three continuous stages: at the first stage, bottom-hole pressure is reduced with water output only; at the second stage, when the pressure further drops, there is a certain amount of methane desorbed from the coal surface, forming isolated bubbles, and thus forms a non-saturation single-phase flow stage, at which gas can't flow, but impedes the flow of water and reduces its relative permeability; at the third stage, a further decline in reservoir pressure causes gas increase and a continuous gas flow, and thus gas-liquid two-phase flow appears. The characteristics of CBM production make it different from the conventional production of oil and gas production. The differences include: reduction of the bottom-hole pressure to the largest extent; drainage of isolate gas and water from the ground before the production; because of the low formation pressure, the pressure of output gas need to be compressed to transport pressure; output water treatment; generally the yield of gas well is low, but the stable cycle is relatively long.

1.4.1.3. Waste Water Treatment in CBM Production

In the process of CBM recovery, a large amount of water will be produced at the same time. In general, the water output is of high salinity with a large amount of suspended solids, which will definitely cause environmental problems without proper treatment. After aeration precipitation to remove cinder in the aeration tank, reduction of iron and organic content, attempt to meet the processing standards by using desalination setting with the supernatant (Anti-dialysis membrane, electrodialysis membrane, ponds or ion exchange method), the following three methods are recommended: ground emissions (CBM produced water will be discharged directly into nearby rivers or used for farmland irrigation), surface evaporation (using ground evaporation ponds to deal with the output water), underground injection (CBM produced water will be injected into the underground again through injection wells). In arid areas, treated water can be used for farmland irrigation; in other areas, it may be dealt with through ground discharge or injection.

1.4.2. The Utilization of CBM

The same as nature gas, the CBM is also a clean fuel gas with high quantity of combustion, which can be used not only as fuel but also chemical raw material.

1) Civilian fuel

Civilian usage is always the primary market for large-scaled utilization of CBM. Because it is of high quantity of combustion and good adjustability, has no needs of cleaning setting and will not erode or jam gas transportation equipment, the CBM is ideal fuel for individual family use.

2) Industrial fuels

In industry, the CBM is mainly used for power plant, manufacturing and auto motor industry. Power generation is an important area for CBM application and it has undergone fast development in the world. The CBM with different consistency can be used by different type of generating equipment.

As a substitute for coal, CBM can also be used to process glass and smelt. It not only has high quantity of combustion but also can improve the environment inside and outside of the factory, and can improve the quality of products.

The technology to use nature gas as vehicle fuel instead of oil has been widely used in some cities, but the problem of insufficient supply is getting more and more serious. It is highly advisable to use CBM in replacement of part of natural gas. Presently, some mines and cities have used CBM from mines as vehicle fuel and obtained good economic benefit.

3) Chemical material

The CH_4 contained in CBM is an important source of chemical material, and can be processed into such chemical products as methanol, formaldehyde, methylamine, carbamide and soot carbon, of which the synthetic ammonia, synthol and hydrocarbon have best market prospect.

1.5. Opportunity to the Chinese CBM Resources Development and Utilization

China is rich in CBM resources, and the CBM development has bright prospects. According to the outcome of the oil and gas resource evaluation, the Chinese CBM resources with burial depth of less than 2,000 m can reach about 35×10^{12} m^3. As a kind of mineral resources, the exploration, development and utilization of CBM in China have a short history. The exploration activities aiming at CBM are far less than those for coal and gas. The CBM development and production have just entered into the small-scaled commercial stage. But the CBM production in the United States has reached 50×10^9 m^3 in 2004. Therefore CBM development and utilization in China are experiencing an unprecedented opportunity as well as difficulties caused by the special geological conditions of the coal seams and the limited CBM transportation and distribution pipelines in China.

1) China has reliable and sufficient resources of CBM

The amount of the CBM reserves in China is enormous, ranking third in the world. With the increasing investment in the CBM exploration and development, the proven CBM reserves in China have been increasing gradually. By the end of October 2005, the Chinese State Reserve Committee has reviewed and approved 4 blocks of an area of 575.95 km^2 with proven CBM reserves of 102.31×10^9 m^3. With the ratio of the proven reserves in the CBM resources considered, the proven rate of the CBM in China is still low and the potential increase in the proven CBM reserves is great. According to the "11th Five-Year Plan of the Chinese CBM (Coal Gas) Development and Utilization", in 2010, the proven CBM reserves in China will be 300×10^9 m^3, which will provide a reliable resource for the CBM development and utilization in China.

2) Demand for high-quality energy resources is booming

With the rapid development of the national economy, the demand for high-quality energy in energy consumption is experiencing a substantial growth in China, and the supply and demand gap for conventional natural gas is becoming more and more apparent. The Chinese government has made the Natural Gas Utilization Policies which set up the utilization order of the natural gas to keep a balance between supply and demand of the natural gas. Like natural gas, CBM is also a kind of clean energy resource with methane as main component, and thus it is reasonably taken as an important strategic complement for the conventional natural gas. It is predicted that the Chinese natural gas supply shortage will reach 8×10^9 m^3 by 2010 [13, 14]. In accordance with the "11th Five-Year Plan of the Chinese CBM (Coal Gas) Development and Utilization", CBM extracted by surface drilling development can reach 5×10^9 m^3 by 2010, which will effectively relieve the supply shortage of the conventional natural gas.

3) Surface drilling and underground CBM extraction are used for the production safety in coal mines

Methane explosion is the main cause of coal mine accidents in China. According to international experiences, CBM development and utilization are the main method to change CBM from being harmful to beneficial and achieve a fundamental improvement in coal mine safe production conditions to curb the mining accidents. The Chinese government pays intensive attention to the coal mine safety issue, and requires that the methane pressure of the coal seams decrease to less than 0.74 MPa and to the condition that the indicators show no outburst danger in coal seams before production through underground gas extraction and surface drilling extraction, when the coal production is conducted in high methane content mines. It is of great significance for the CBM development and utilization to prevent the mining accidents.

4) Pressure for energy saving and emission reduction will encourage CBM development and utilization

The Chinese "11th Five-Year Plan" proposes the binding targets that the energy consumption per unit GDP decreases by 20% and the main pollutant emissions reduce by 10% in the period from 2006 to 2010. The energy consumption per unit GDP in 2006 was required to decrease by 4% and the main pollutant emissions reduce by 2%. However, according to official statistics, the Chinese energy consumption per unit GDP of 2006 dropped only by 1.2%, while the chemical oxygen demand and sulfur dioxide emissions are still growing [15]. It is clear that the current situations of energy saving and emission reduction in China are still a challenge. The irrational energy consumption is one of the resistance to energy saving and emission reduction. Currently, coal is still the main energy source in China, which makes it difficult to achieve a higher level of energy utilization efficiency and to reduce the emission of pollutants. The CBM is one of high-quality energy resources with high caloric value, and methane in the CBM is also a main greenhouse gas, only second to the carbon dioxide, and therefore intensifying the CBM development and utilization can not only take use of the efficient, clean features of the CBM, but also significantly reduce greenhouse gas emissions.

5) Policy environment for the Chinese CBM development and utilization is becoming better

With the gradual increase of Chinese CBM activities, the law and policy environment for the CBM operation is continuously improved. The Chinese government has made the CBM law and regulation framework to guide and regulate the development of the CBM industry, including mining license control, external cooperation, taxation, etc. In recent years, with the scale expansion of CBM exploration and development, some new problem have risen, such as: CBM and coal are symbiotic mineral resources and their mining licenses are easy to overlap, which result in the uncontrollable situations between coal mining and CBM production; in the early period of CBM development, the productivity is lower and the payback period is long, which fail to motivate investing enterprises. According to the international experiences, these are the main problems to hinder the development of CBM industry. In 2007, China's Ministry of Finance and the Ministry of Land and Resources published two regulations: "the Implementation View of the Ministry of Finance on the Subsidy Suitable for the CBM (Methane) Development" and "the Notice on the Strengthening Management of the Integrated Exploration and Development of the Coal and the CBM". The regulations limit the mining license and the method to subsidize CBM sale is specified in these regulations. The publications of the regulations create a very favorable policy environment for the Chinese CBM development and utilization.

To develop its CBM industry, China needs to take the opportunity and learn from the experiences of CBM industry development of successful countries in the field, conduct assessment of coalbed methane technology and process, make proposals to government policy makers and to investers through the geological constituency and economic evaluation of the China's CBM resources.

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Chapter 2 World-wide CBM Development and Experiences

In early 1980s, the successful surface CBM extraction in the United States initiated the CBM industry in the world. Since then, more and more countries have realized that CBM can be fully developed and utilized as a clean energy source. Following the United States, Canada, Australia, UK etc. started to develop their own CBM industry and among them Canada and Australia have started commercial development and application. Their experiences in the aspect will help China to develop its CBM industry in a more efficient way.

2.1. Overview of CBM Resources in the World

It is found that 74 countries are rich in CBM in the world. According to the estimation of IEA, the total CBM reserves are 260×10^{12} m^3. As main coal producing countries, Russia, Canada, China, the United States and Australia hold vast CBM resources in excess of 10×10^{12} m^3. Table 2.1 shows the CBM resources in main coal producing countries.

Table 2.1 CBM resources in main coal producing countries in the world

Country	CBM resources ($10^{12}m^3$)		Country	CBM resources ($10^{12}m^3$)
Russia	17~113		Poland	3
Canada	6~76		UK	2
China	31.46		Ukraine	2
United States	21.19		Kazakhstan	1.1
Australia	8~14		India	0.8
Germany	3		South Africa	0.8

Source: China United Coalbed Methane Co., Ltd.

2.2. Overview of CBM Resource of the Important CBM Regions

The United States is the first CBM exploitation country in the world. Its CBM industry started in the 1970s. After mining test of over 20 years, it successfully conducted surface exploitation in the late 1980s and early 1990s. After the successful commercial CBM development in the United States, the whole world has gradually realized the CBM is a valuable resource and many countries with rich CBM resources, such as Canada, Australia, China, UK, Russia, India, etc, have started their CBM exploration and development. All of them have made progress to some extend.

2.2.1. CBM Resources in European Countries

2.2.1.1. CBM Resources in UK

Coal resource is comparatively rich in UK, and the degree of exploration is relatively high. The recoverable reserves are 2.5×10^9 t, accounting for 0.2% of total reserves of the world. According to the distribution of Carboniferous coalfield, it can be divided into 4 areas: South area, Middle area, North area and Scotland [11], and the gross CBM are 2×10^{12} m^3. The south Wales coalfield is the main coalfield in the South. It contains rich coal beds, but it also has many faults and drapes. The Middle area's main coalfield is Yorkshire-Nottingham County basin with comparatively simple structure and mostly bituminous coal. The main basin in the North is Durham Basin [10]. As to the Scotland, it contains mostly high volatile bituminous coal with CBM of 560×10^9 m^3, and there are many faults inside [11].

2.2.1.2. CBM Resources in Germany

Ruhr, Sal area and Aachen and Ibbenburen contains most of the coal resources in Germany. The main fields are Ruhr, Sal coal fields. The average content of CBM in these 4 hard coal bed is 10 m^3/t to 24 m^3/t (the top content is up to 60 m^3/t) and the total content of CBM is 3×10^{12} m^3.

2.2.1.3. CBM Resources in France

The CBM resources in France mainly are distributed in Lorraine basin, Alea basin and

Limagne basin [11].

2.2.1.4. CBM Resources in Other Countries

Poland is the forth hard coal producing country in the world. Upper Silesia, down Silesia and Lublin basin are all rich in CBM [7], with gross resources of 3×10^{12} m^3, mostly present in Upper Silesia basin [10].

CBM is not rich in Belgium, and Campine basin in the south is the main producing area. There are some difficulties in draining and drilling, because of many faults in the layer.

2.2.2. CBM Resources in Canada

The CBM resources in Canada are mainly distributed in western Alberta sedimentary basin, which is part of Rocky Mountain foreland basin and geographically mainly located in the Alberta Province with a small part in the British Columbia Province. With coal resources of more than 1×10^{12} t, the basin area coverage is 130,000 km^2 and the coal thickness is 10 m to the largest extent. Because the most western part of the basin has the most burial depth of the coal and the most metamorphism, the reflection is 2.0%, but the metamorphism in the eastern part is low. The coal rank ranges from lignite to high metalorphic bituminous coal. The potential gas resources held within these coal deposits are estimated to range from 6×10^{12} m^3 to 76×10^{12} m^3, and it centralizes in four main coal zones. The Ardley Coal Zone of the Plains is undergoing CBM exploration and production piloting. Much of this effort is within the west-central Pembina area. Horseshoe Canyon Formation coals in south-central Alberta is the first to conduct commercial CBM production in large scale. Although similar in geographic distribution and coal quality to Horseshoe Canyon coals, Belly River Group does not contain clear gas potential. The deeper Mannville coals have the most gas concentrations of Alberta coal; however, compared to the other three coal seams, coal in this region is relatively deep and have lower permeability[1~5].

2.2.2.1. Horseshoe Canyon Formation

The Horseshoe Canyon Formation high production zone lies between Calgary and Edmonton, 100 km in length from east to west and 300 km from south to north with CBM resources exceeding 2×10^{12} m^3.Three coal zones are identified in the Horseshoe Canyon Formation: the lowermost Drumheller Coal Zone, the Daly-Weaver Coal Zone and the uppermost Carbon-Thompson Coal Zone. The Horseshoe Canyon Formation is Upper Cretaceous and the color is purple; Burial depth of its coal seams is about 200 m~700 m only. The coal seams here are no less than 30 layers and the cumulative thickness is about 30 m. The thickness of individual layer ranges from 0.1m to 3.0 m. Thick net coal accumulations are present in the Drumheller Coal Zone, with local accumulations up to 18 m and the average of 8 m. Individual seam thickness is 1 m~2 m in average, although greatest net coal seams may be up to 5 m. In the Horseshoe Canyon Formation rank of coals at shallow depths is subbituminous B but in the central Plains region, the majority of coals are in rank of high volatile C bituminous. Coal rank increases westward and northward, where a rank of high volatile B bituminous exists. The gas content in Horseshoe Canyon Formation is 1 ml/g ~ 5 ml/g and it increases with the increasing of coal rank .The reflection is 0.4%~1.5% and the abundance is 150×10^6 m^3/km^2.

Because Horseshoe Canyon Formation coals are “dry coal” of reasonalbe depth, and the costs are low and there is no need to discharge water, it is the most active target formation in Canada. Generally, the output per well is 2.1×10^3 m^3/d ~ 4.3×10^3 m^3/d, and the average is 2.83×10^3 m^3/d. In the high-yield Corridor District, the average output per well is 3.5×10^3m^3/d. In the highest yield region, the central region, output can reach 3.5×10^3 m^3/d.

2.2.2.2. Mannville Coal Zone

The Lower Cretaceous Mannville Group contains several important coal deposits, and the whole zone can be divided into upper, middle and lower groups. The Upper Mannville Group contains two to four coal subzones, with maximum resources in Mannville Coal Zone of 9.06×10^{12} m^3. The general coal depth in Mannville is above 800 m in the Plains, which locates near surface in the northeastern area of the province. Coal rank ranges from lignite at Firebag, and subbituminous to high volatile bituminous at depths of less than 2000m in the Plains. The Mannville coals vary in thickness, from less than 2 m net coal to greater than 12 m net coal. Thickest net coal occurs in the Red Deer area, with 6 m~12 m of net coal. In the deep basin and westward toward the Foothills, net coal thickness can exceed 16 m with average net coal range of 2m~6m. The coals in Forebag Coal Zone are thin and shallow and the net coal thickness ranges from less than 1m to greater than 11m over short distances. The coal in Mannville has higher gas contents than that of the shallower Ardley coals, which ranges from 3 m^3/t in the Plains, up to 20 m^3/t in the Foothills, and gas concentrations vary significantly over a short distance. For example, the gas concentrations of Mannville coals in the Plains of northwestern Alberta are between 4 m^3/t~8 m^3/t in the general depth range of 800 m~1000 m, slightly lower than those in the central Plains, which are between 8 m^3/t~10 m^3/t at a depth range of 1000 m~1400 m. This value drops dramatically toward the eastern margin of the province, where coal rank is low and the coals are shallow. Test results indicate that the Mannville coal seams have low permeability, in the central plains, which is only 0.1×10^{-3} μm^2~0.2×10^{-3} μm^2. Permeability appears slightly higher in the eastern part of the Plains, where permeability is 1×10^{-3} μm^2 ~ 4×10^{-3} μm^2. In the northeastern Plains, permeability is even lower than the central Plains, reportedly less than 0.1×10^{-3} μm^2. Higher permeability (1×10^{-3} μm^2 to 3×10^{-3} μm^2) was reported in more recent tests of Mannville coals in the central Alberta Plains, only 500 m away from the former testing site. This also adds proof to the variability in permeability across the province. Several pilot projects were conducted in this formation. These pilots initially produced large volumes of saline water, but after a period of time (several months) more gas is produced.

2.2.2.3. Ardley Formation

Ardley Coal Zone is within the Scollard Formation, this coal zone consists of four individual subzones. All seams are present in the western and central parts of the Plains, and the seams are laterally connected. The average thickness of the Ardley Coal Zone ranges from 14 m near outcrop to greater than 200 m at the western margin of the Plains. Furthermore, the number of seams increases from an average of four near outcrop to as many as 18 at depth near the western limit of the Plains. Coal rank within the Ardley ranges from subbituminous near outcrop to a maximum of high volatile B bituminous in the western deepest areas, and reflectance in most of the area underlain by Ardley coal falls within 0.5%~0.65% (high volatile C bituminous coal). The Ardley Coal Zone contains the thickest net coal accumulations in the Plains, exceeding 20 m in some areas. The exploration and exploitation activities are mainly concentrate within two most favorable areas, and within these two areas, gas-in-place exceeds113×10^6 $m^3/1.6$ km^2. The current production in Ardley Coal Zone is mainly 0.4×10^3 m^3/d ~2.8×10^3 m^3/d, and the average is 1.0×10^3 m^3/d.

2.2.3. CBM Resources in Australia

The coal recoverable reserve in Australia is 39.9×10^9 t, and the average CH_4 content is 0.8 m^3/t ~16.8 m^3/t. Generally, the burial depth is less than 1000m, and the permeability arranges from 1×10^{-3} μm^2 to 10×10^{-3} μm^2. The CBM resources in Australia are 8×10^{12} m^3~14×10^{12} m^3, and now it is the most active country of CBM development after The United States. The early activities mainly focus on several coal basins of Permian-Triassic in the east of Australia, including the Sydney Basin, the Gunnedah Basin, the Bowen Basin and the Galilee Basin [1,2,6,7].

2.2.3.1. Sydney Basin

The Sydney Basin is a Permian retroarc basin in New South Wales of Australia. The coal seams include upper Permian Illawarra Formation and lower Permian Greta Formation. The total thickness ranges from 85 m in the north to 9 m in the south, and the average thickness is 30 m. The Greta Formation extends for 190 km along the north of the basin with the thickness of about 15 m which drops to less than 3 m in the basin center. The coal bearing area in Sydney Basin is 49,000 km^2, the Bituminous coal reserves located in a depth of less than 1,800 m is about 1.2×10^{12} t, and 50% of them are in the depth of less than 900 m. The estimated CBM resources are 3.68×10^{12} m^3. Gas content in the Sydney Basin can reach 18 m^3/t at most, but it varies greatly within this region. Coal seams are mainly high and low volatile coal formation, whose R_0 is 0.7%~1.9%, most of which is brown coal. Permeability is low, varying between 0.05×10^{-3} to 5×10^{-3} μm^2. Coal bearing pores range in size from over 50nm to less than 2 nm in diameter, depending on coal composition and rank.

2.2.3.2. Gunnedah Basin

Gunnedah basin lies in the South of New Wales, and it forms the central part of a major foreland basin system in eastern Australia that extends over 1,500 km from the Sydney Basin in the south to the Bowen Basin in the north. The Gunnedah Basin contains more than 500×10^9 t of coal in the Permian, among which, about 28×10^9 t of recovering potential. The coal is of high volatile bituminous rank, with a mean maximum vitrinite reflectance between 0.56% and 1.1%.There are two main coal-bearing sequences containing CBM resources in the basin: the Early Permian Leard and Maules Creek Formations, and Late Permian Black Jack Group with the thick, widespread Hoskissons seam in the lower part of the section. On the Early Permian coals in the northern part of the Gunnedah Basin, the coals are saturated and highly permeable. Gas content is high, with an average of 14.8 m^3/t in clean coal and about 16.9 m^3/t in dry ash-free coal. Post-stimulation CBM gas production varies from 200mcf/d to 1.2mmcf/d. Gas content of clean coal in Black Jack Group is 9.1m^3/t and 10.7m^3/t on a dry-ash free basis. In ACMY, the southern part of the Gunnedah Basin, gas content of Black Jack Group coal reaches up to 8.9m^3/t on a raw coal basis and 15.4 m^3/t on a dry ash-free basis.

2.2.3.3. Bowen Basin

The Bowen basin lies in the east of Queensland, and the main Permian coal seams include Reids Dome, Collinsville, Moranbah and Rangal. The depth of the coal seams which are overlapped by the Surat basin is mostly over 2200 m, and only that in the east and west edge areas of Taroom trough is shallow. The CBM resources in Bowen Basin are as great as 5×10^{12} m^3 and the average gas content is 10m^3/t. The main exploration difficulties are low permeability and high CO_2 content in part areas. The coal rank gradually increases eastward, and which can reach semi-anthracite and anthracite coal.

2.2.3.4. Galilee Basin

The Galilee Basin is a cratonic infaulting basin in the center of Queensland covering an area of 234,000 km^2. Coal seams are mainly distributed in the Early Permian Aramac Formation and the Late Permian Betts Creek Formation. The up-to-54 m thick Aramac Formation mainly lies in the east of the basin and forms swampy environment. Betts Creek Formation is distributed even more extensively where coal seams are deposited in huge prograded delta or alluvial fan environment with 1.5 m~9 m of individual seam thickness. The coal seams of Galilee Basin are shallow, and about 4800 km^2 of which in the east part are in favorable drilling area. Gas content is low, and the average is 2.6 m^3/t (drilling test result), but part of the area can reach 4 m^3/t. Coal seams contains low-rank high volatile bituminous coal. Permeability varies in a large range, from less than 0.1×10^{-3} μm^2 to 200×10^{-3} μm^2. Generally, the gas contents are low with an average of 2.6 m^3/t (drilling test results), and parts of the area can get 4 m^3/t.

2.2.4. CBM Resources in the United States

The U.S. has rich CBM resources. In 2000, GTI estimated that the CBM resources in the U.S. were 21.19×10^{12} m^3. Over 80% of CBM resources concentrate on the Mesa Cenozoic coal-bearing basins in the Rocky Mountain in the western U.S., including Raton Basin, San Juan Basin, Powder River Basin, Uinta Basin, etc. The CBM resources in these basins make up more than 80% of the total CBM reserves in the country. The rest mainly distributes in the Appalachian coal-bearing basins (including N. Appalachian Basin, Cent. Appalachian Basin, Black Warrior Basin, etc) in the eastern U.S. and the Carboniferous coal-bearing basins (including Illinois Basin, Arkoma Basin, Forest Basin, etc) in the central U.S. Currently, commercial CBM development has been carried out in 15 bearing basins, and the main production comes from three basins which are Black Warrior Basin, San Juan Basin and Powder River Basin [1,2,8]. Main CBM Basin Characteristics in the United States are as Table 2.2.

2.2.4.1. Black Warrior Basin

The Black Warrior basin is a late Paleozoic foreland basin that lies in the adjacent place to the juncture of the Appalachian and Ouachita orogenic belts. Its coal-bearing area is $15{,}500\times10^3$ km^2 and the CBM reserves in the Black Warrior Basin are about 570×10^9 m^3, among which the recoverable reserves are about 280×10^9 m^3. CBM resources of high economic value are in the upper part of the Pottsville Formation, which is of Early Pennsylvanian age. The productive Pottsville section ranges in thickness from about 600 m in the northern CBM fields to more than 1400 m in the southern fields. The maximum thickness of single coal seam is 2.4 m, and the maximum thickness for a single well is 7.6 m. Coal rank varies regionally from high volatile bituminous in the south to low volatile bituminous along the southeastern basin margin, and the east-central part of the basin contains coals of the highest rank. The reflection is about

0.7%. The permeability of the coal seams is from 0.1×10^{-3} μm^2 to 20×10^{-3} μm^2, and the average is from 1×10^{-3} μm^2 to 5×10^{-3} μm^2, and the gas content is generally about 20 m^3/t.

Table 2.2 Main CBM Basin Characteristics in the United States

Basins/Criteria	Black Warrior	San Juan	Powder River	Raton
Area	Al, MS	NM, CO	WY, MT	NM, CO
Depth Metres Feet	 1200 4000	 1980 6500	 750 2500	 1200 4000
Coal Thickness Metres Feet	 6~9 20~30	 2.4~4.6 8~15	 1~30 3~100	 0.5~2 2~5
Permeability ×10^{-3} μm^2	<30	<50	<1D	<10
Estimated CBM esources ×10^{12} m^3	0.57	2.38	1.1	0.28
Estimated Recoverable Reserves ×10^9 m^3	123.11	327.35	264.01	98.85
Gas Content cc/gram scf/ton	 1.0 350	 13.4 430	 0.9 30	 9.0 300

Source: GTI Canada, MGV Energy Inc, Geological Survey of Canada.

2.2.4.2. San Juan Basin

The San Juan Basin locates in north western New Mexico and south western Colorado, USA, and it is a Laramide structural depression. The San Juan Basin is 100 miles from south to north and 90 miles from west to east, covering an area of 19.425 km^2. San Juan Basin's geological characteristics are as follows: the coals are thick and broad, the ranks are from middle to high, the permeability is appropriated, the water production is from middle level to high level, the coals are of ultrahigh pressure, and the closure property of the bed stratum are good. So San Juan Basin is thought to be the most prolific coalbed gas basins in the world. The Fruitland Formation is the major producing CBM horizon. It crops out along the basin's western, southern and part of its eastern edges, and conformably overlain by the Kirtland shale throughout most of the basin. The CBM resources in the Fruitland Formation are proved to be 1.42×10^{12} m^3. Fruitland coal rank ranges from subbituminous in the southern part of the basin to medium and low-volatile ituminous in the northern part of the basin, but coals near the Colorado border, thermally altered by the San Juan volcanic complex, are of a higher rank (high-volatile bituminous).The maximum depth of the Fruitland Formation is about 2200 m and single seam can reach up to 9 m, and cumulative thickness of the coal seams are 11 m ~ 34 m. The gas content of the coal seams is 9 m^3/t ~ 17 m^3/t and the general permeability of the coal seams ranges from 3×10^{-3} μm^2 to 25×10^{-3} μm^2.

2.2.4.3. Powder River Basin

The Powder River Basin lies in north-eastern Wyoming and south-eastern Montana, and north of the Rocky Mountains, covering an area of 66,800 km^2 and with CBM resources of about 1.1×10^{12} m^3. The basin is an asymmetrical synclinal basin extending from south to north, the west of which is steep and the east flat. The basin has simple structure with no large-scale fold or fault. The accumulated thickness of the Powder River Basin is 115.9 m~137.3 m. Coal rank is low and it is mainly brown coal and cannel coal, the reflectance is 0.28%~0.45%. Gas content is less than 2 m^3/t, but the permeability is high, which is about 500×10^{-3} μm^2~1000×10^{-3} μm^2. One of the main coal seams is the Fort Union Formation whose total thickness is 24.4 m~45.8 m and burial depth is 76.3 m~457.5 m. The other is the Wasatch Formation whose total thickness is 91.5 m, single seam thickness commonly reaches 30.5 m and burial depth 305 m~610 m. Cumulative thickness is 115.9 m~137.3 m. The coals contained are low-grade metamorphism coals as brown coal and fat coal. Gas content is less than 2 m^3/t. Permeability is as high as 500×10^{-3} μm^2~1000×10^{-3} μm^2.

2.2.4.4. Raton Basin

The Raton Basin lies in south-eastern Colorado and north-eastern New Mexico, and it is an asymmetrical, south-north-trending synclinal basin. The basin is 128 km long from south to north and 80 km broad from west to east. The total area is 5,700 km^2 and CBM reserves are about 280×10^9 m^3.The maximum depth of the basin is 3810 m, and the coal seams are the upper Cretaceous Vermejo Formation and the Eogene Raton Formation, which belong to littoral plain deposition. The coal seams develop into 4~10 layers with an average single thickness of 0.6 m~1.5 m (3.6 m at the most) and cumulative thickness of 6 m~12 m. Due to thermal metamorphism by magma, the coal metamorphism grade of the seams is high and it contains coals like kennel coal, gas coal, fat coal and coking coal. Gas content is 7.1 m^3/t~16.1 m^3/t and permeability is as high as 10×10^{-3} μm^2~50×10^{-3} μm^2.

2.2.5. CBM resources in Russia

Russian coal reserves are the second in amount in the world, and own the most CBM reserves. Kusbass and Bochola coalfield are the main coalfields in Russian. The All-Russian Gas and Gas Fields Technology Research Institute estimated that Coal reserves in these two fields are respectively 13.1×10^{12} m^3 and 1.9×10^{12} m^3 [27]. But with the growth of coal mining, large number of CBM is emitted. Kusbass Coalfield emits annually as much as 1×10^9 m^3~2×10^9 m^3 of CBM.

2.3. CBM Exploration and Production Technology in the Main CBM Regions

2.3.1. CBM Exploration and Production Technology of EU

2.3.1.1. Key CBM Exploration and Production Technology of UK

In UK, the most popular method is vertical drilling through many layers, and there are three means for pruducing CBM as shown in Figure 2.1. The hole was drilled upward by a given angle, and in some situation, it can be drilled downwards into coal bed which has already been extracted (exhausted area) [12]. This method was used in thirteen coal mines among the sixteen coal mines in UK that has done gas Drainage. Taoer coal mine can be taken as an example.

Power line logging service was used during borehole survey in UK. They use clean water or foam to drill wells, but the effect is not good in fragile layer. The continuously flexible pipe drill has already been applied widely to small well bore and perforation. It also use clear drilling to optimize recycle of CBM in virgin area.

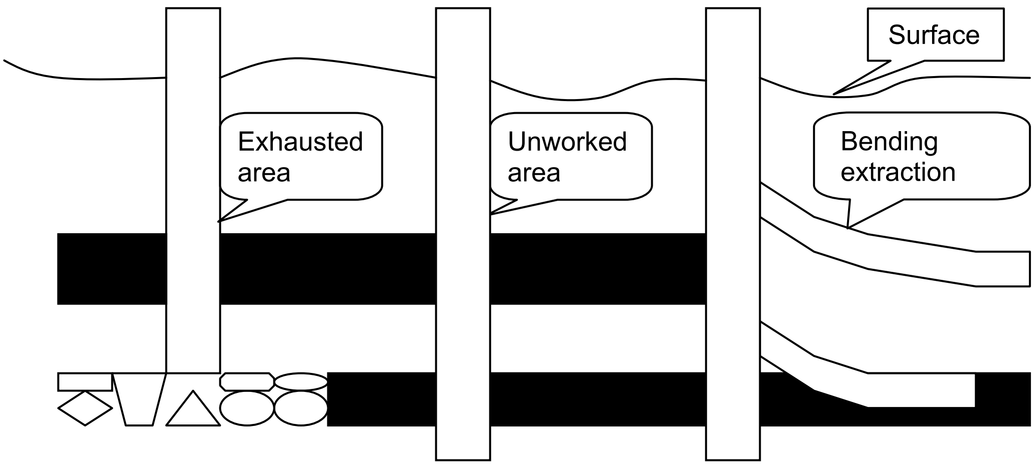

Figure 2.1 Sketch figure of vertical drilling through many layers (Hu Qianting, 2003)

UK natural gas Co. has used new technology in well drilling and completion by utilizing multi-driving directional drilling technique. This technology is used to drill many holes with 30° or 45° from ground with less expenditure.

The permeability of the coal seams is low in England, and thus it pays more attention to the exploit ation of coal beds with low permeability, so the multi-branched well is good. In 1996, England petroleum Co. developed a well control technology for multi-branched well. Meanwhile, it put forward a set of calculation formula in well control parameter such as maximum permit kick quantity and pressure, worked out frame of branch well control, indicatesd the problems which should be observed and the differences between t branch well control, convent vertical well, orientation well, horizontal well and multi-branched well [13]. We can drive CBM out by injecting CO_2 to enhance recover, but the effect is as expected because of low permeability rate of the coal seam.

2.3.1.2. Key CBM Exploration and Production Technology in Germany

Ruhr coal field has bituminous coal from high-grade to low-grade. Many well was drilled towards Rhine Westphalia coal seam. The annual production adds up to $20\times10^9\,m^3$~$30\times10^9\,m^3$. Sal coal field belongs to Saar-Lorraine coalfield geologically whose exploitation is targeted to the Suercibahe coal layer.

In Ruhr coal field, a test was run before the hydraulic fracture in the bore hole, but the gas permeability in test area was so low that hydraulic fracture was stopped [14].

Saar coal Co. and Remote Coal Gas Company drilled 2 test wells in Saar coal field. The bottommost depth is 1900 m. Hydraulic fracture was used to improve the gas permeability. The effect of one well is better than the other, whose production reached 6000 m^3 [14].

2.3.1.3. Key CBM Exploration and Production Technology in France

Kate Energy Company drilled 2 test wells in the central highlands coalfield, both adopted the gelled fracture fluid. Alsace I well was seriously blocked by the coal dust, so it produces little methane. Fracturing was performed six times among the 25m-thick coal bed in the Alsace II well and achieved good result.

The multi-branched well is widely used in France, but the rock in the coal seams was seriously damaged, and for this reason, it is difficult to drill wells. ELF Company designed a downhole multi-branched device, the main part of which is a three-slot receptacle for drilling 3 different branches in the same bore hole (the bore can also be changed to double or multiple punching). The diameter of each bore is 63.5mm and this device is put down to the depth above the gas layer, and then cementing it with the technical casing. Then a special connecting tool is lowered down into the three-slot receptacle and connects the three-slot receptacle with surface by a riser of 139.7mm. Drilling tool is put down into the bore through the riser of 139.7 mm, and drills a bore of 63.5 mm, and then the connect tool and riser are transferred to another bore by the guide link on the upper part of the three-slot receptacle in order to drill the second and third branch. Then a well with the slotting tail pipe of 50.8 mm is completed, and the slotting tail pipe is hung on the three-slot receptacle in the technical casing. This device was used to drill a three-branched well in the Escha field in Alsace area. The expense was twice as much as the well around, but its production was 5 times higher [13].

Besides, other countries such as Poland, Belgium and Hungary are all trying to exploit CBM recently.

Presently, Poland adopts comprehensive technology to make the recycle of CBM in the fastest speed, and the methods include recycling CBM by drilling ground well and down hole well during pre-exploitation, exploitation, post-exploitation with the production ratio of 80%~90% [11]. Most wells in Poland need hydraulic fracturing and the permeability varies dramatically, so water needs to be pumped in all the wells. Mikan CBM Co. of Poland has drilled several test wells and conducted hydraulic fracturing several times.

Belgium used rolling bit to drill wells in Campine and then several times hydraulic fracturing followed. They mostly adopt gel liquid and nitrogen foam for the fracture [18]. At present, only 11% CBM can be carried out through 100 CBM wells, which accounts for 10% of natural gas in Belgium [10].

2.3.2. CBM Exploration and Production Technology in Canada

Canada has rich CBM resources. Technical innovation plays an important role in the quick development of CBM industry in Canada next to the policy and economic factors.

Most coal in Canada is low rank coal, with characteristics of low gas content, tight formation, low formation pressure and low permeability, because of which, fracturing is needed before commercialized production. At the beginning, conventional fracturing methods including hydraulic fracturing (with no proppant), N_2 foam fracturing and liquid CO_2 fracturing (with no proppant) were adopted, but as a result, there was little fracturing fluid flowing back and almost zero gas production. Afterwards, according to the CBM resource conditions and successful experiences of shallow gas development of this country, coiled tubing drilling and high flow rate N_2 foam fracturing technology were developed and successfully applied. By using multi-branched pinnate horizontal well technology from The United States, cost was cut down and production improved.

(1) Coiled tubing drilling technology

Coiled tubing drilling technology was firstly used in conventional reservoir drilling and operation. Coiled tubing drilling has advantages as follows: a. reducing drilling cost; b. lessening environment pollution, decreasing drilling accidents and saving time of drilling fluid recycle; c. suitable for drilling in high pressure formation, under balance drilling and slim hole drilling [20]; d. enhancing recovery of oil and gas [21]; e. suitable for shallow reservoirs.

Generally, CBM reservoir is shallow and damageable. Coiled tubing drilling could not only reduce the reservoir damage, but also cut down the drilling cost.

(2) High flow rate N_2 foam fracturing technology

Foam fracturing technique is an effective measure of stimulation and completion in the reservoirs with low pressure, low permeability and water sensitivity. It has advantages of little reservoir damage, low liquid content, little filter loss, rapid flowing back and so on. Canada's N_2 foam fracturing technology has outstanding characteristics: a. high flow rate, up to 500 m^3/min~1000 m^3/min; b. N_2 only, with no sand as proppant; c. efficient, it only takes 4 days from drilling to production, including 1 day for drilling, 2 days for well completion and 1 day for fracturing. N_2 foam fracturing could not only avoid reservoir damage by fracture liquid, but also accelerate CH_4 desorption and enhance CBM recovery because of N_2 injection. As a result, cost is cut down and production is increased.

(3) Multi-branched pinnate horizontal well technology

The multi-branched well technology of Canada has used the United States' experiences for reference, which plays an increasingly important role in CBM production due to its advantages like larger drainage area, high single well production, low unit production cost and small land occupation.

2.3.2. CBM Exploration and Production Technology in Australia

Technology of the United States is not suitable for CBM development in Australia because of the poorer coal property than that in the United States. Therefore, new technology needs to be developed to accelerate the CBM industry of Australia.

Firstly, do research on in-situ stress for development block selection. Because of high gas content and low permeability coal in Australia, it is critical to forecast blocks of high permeability for development. After a few years of research, it is proposed that looking for high permeability blocks should make use of stress numerical analysis (simulation) based on crustal in-situ stress measure. What's more, the soundly coal data base could help blocks selection [11,23].

Secondly, developed MRD (Medium Radius Drilling) technology and (TRD) Tight Radius Drilling system are similar to CDX drilling technology.

MRD technology was tested successful at Moranbah in 2002 by CH_4 Company. This technology is firstly to drill a vertical well, then drill a directional well. This technology is relatively mature and the costs are the same or even lower than drilling vertical wells but much less than drilling with CDX technology. It is suitable for coal burial depth of 500 m~700 m and able to drill 20 branched well at most. It can drill rapidly that to drill a 200 m well just takes 4 hours. Of cause, it has disadvantages, and for example, the length of lateral horizontal wells could just reach 200 m~500 m, however, it can reach up to 1200 m by CDX.

TRD technology was developed by CMTE (Centre for Mining Technology and Equipment) of Australia in 2001. It is also to drill a vertical well and then drill lateral multi horizontal well holes of a length of about 180m in any direction. If there are multi coal seams when drilling vertical wells, lateral horizontal wells can be drilled in all seams there, which can improve the permeability of the seams and increase the CBM production [24].

Thirdly, Fracture technology emphasizing fracture effects: study on coal bed stress to design fracture simulation; cutting a directional canal and shooting directionally before fracturing to release the stress; using the river fracture treatment to ensure the connection between fracture split and face cleat a week later; emphasizing the effects of fracture rather than the scale of fracture.

Fourthly, develop drainage and gas production technology of low cost. In this technology, gas engine is used to drive wellhead power unit to drain water and reduce pressure in order to realize the continuous production of CBM well. Solar energy was used to communicate the data in order to reduce the pre-production cost. Running at low cost in a long time is good for evaluating production capacity exactly.

Fifthly, use low cost drilling rigs in CBM to reduce the individual well cost for the deliverability blocking of CBM individual well. The LF90 drilling rig is introduced to reduce the cost. It uses the top drive technology and can reach a maximum depth of 1000 m, and the cost of the drilling rig is only about 300,000 USD and only 2 operators are needed. The cost for a 600 m-vertical well is only 120,000 USD.

2.3.4. CBM Exploration and Production Technology in the United States

Both the production level and the industrialization of CBM in USA rank top in the world. So the development status of the coal-bed methane in the United States basically represents the new development in other countries. The main exploitation and production technologies of CBM in the United States as follow:

1) Conventional drilling and penetration fracturing: long term drainage with huge well group. Experiments show that it is an economical and feasible method to improve the output of single CBM well. The daily output of a single CBM well is only about one hundred m^3 in San Juan basin, and it came up to $5\times10^3\ m^3$~$7\times10^3\ m^3$ after three years drainage with seventeen wells. There are three wells in a group in Ewing tower basin, and the single output of CBM is about one thousand m^3 while the single output is between four and ten thousand m^3 after three years' drainage to the group with 23 wells.

2) Fracturing stimulation technology. It can generate many extended cracks by fracturing. The output was improved by five to twenty times and the effect is very notable. There are some characteristics to bubble fracturing with carbon dioxide, such as low mass production, low filtration rate, high width generation capacity and low damage to coal bed. Preferable effect has been acquired by bubble fracturing with carbon dioxide by schlumberger in the United States. Fracturing with polymer adopted by Halliburton Company has the followed merits: less glue content, high prop carrying capacity, low damage to the coal bed, easily to gel out and low filtration rate. Resin is used as proppant which can reduce the back flow of sand and acquire high sand consolidation.

3) Directional pinnate horizontal well technology [16]. It is the patent technology of the CDX company. It successfully developed a new type of drilling system called "directional pinnate horizontal well of Zigzag type" by using some key technology such as the optimization design to well diagram and trajectory, articulated drilling assembly, seal bore packer whipstock, down hole motor and the drilling mud. U.S. Steel Corporation has applied the system in a CBM project in West Virginia and obtained ideal effect.

4) Air drilling technology. The technology can reduce the damage to coal bed and protect it, cut down the drilling cost and shorten the drilling period. In order to broach the coal bed in underbalanced way, air, gas spray, aerated mud and formation water are used as the drilling mud. Barefoot completion is used for the well. The air drilling technology increased the number of production wells in the United States which is the bases to the increase of CBM productivity in the country.

5) Bare hole cave completion technology. The technology is mainly suitable for the coal bed with high permeability, and the output of a single well is between 3 to 20 times of the output from the wells completed by penetrating and hydraulic fracturing. The cost of it is lower than fracturing. But it is not fit to the coal bed with low permeability. It is indicated by practice that

the permeability should be higher than 5×10^{-3} μm^2. There are four thousand wells in San Juan basin, one third of which were completed by barefoot completion, and the accumulated output of the wells is 76% of the total output.

6) Enhanced recovery technology by gas injection. CBM is made up of methane, carbon dioxide, wet gas, nitrogen gas, hydrogen gas and hydrogen sulphide. Methane is the main composition in CBM with the proportion of about 93%, and more than 95% in adsorption state. The adsorption ability and adsorbance is different to different gas. The recovery can be improved by reducing the pressure and adsorbance of methane [21]. Some the U.S. companies such as Amoco, Meridian adopted the technology by injecting carbon dioxide and nitrogen gas to enhance the recovery of CBM. In this way, some low production wells were successfully changed to high production wells.

7) Developing advanced numerical simulation software. Similar to the normal sandstone reservoir, the numerical simulation technology is a kind of commonly used method in CBM exploitation. It mainly provides data to the testing production, design of development plan, dynamic prediction to the plan and the economic evaluation to the exploitation effect with the simulation results about daily output of gas and water, total output of water and gas, the peak of gas, rational spacing between wells and so on. The professional software in the United States CBM industry includes COMET3D and COALGAS.

2.3.5. CBM Exploration and Production Technology in Other Countries

2.3.5.1. CBM Exploration and Production Technology in Russia

In Kusbass, CBM was initially extracted through a tunnel from the main coal seam gas drainage drilling and mining wear layer to layer CBM drainage. But the efficiency is lower. Generally no more than 20%.While after the local surface wells were used for exploring CBM, Pumping greatly enhance the efficiency, which is up to 60%~80% [27].

The CBM exploration in Russia is now mainly using vertical well technology. In 1998, Russian drilled two ground test CBM wells in Kusbass coalfield. The depth is up to 1350 m. Experimental results show that the local CBM development has good prospects. In 2003, Gazprom companies drilled four test wells in the region and made further technical preparations for the exploration of CBM, which attained good results. Then they planed to conduct large-scale commercial exploration in this region.

They mainly used hydraulic fracturing technique to stimulate production in Russia. But it is worth noting that the various factors in fracturing process might cause certain damage or pollution to the production layers. There emerges a new fracturing technology: electric steam output formation fracturing technology in Russia [28].

Although Russia has started the commercial exploitation of CBM, its CBM exploration work at the ground is still at an early stage, far from industrialized production. With Russia's relaxation of policies to attract foreign investment and the continued application of new technologies, the process of the CBM exploration and development is gradually speeding up. The government shows increasing intention to develop CBM and new markets are being developed continually.

2.4. Development of CBM Industry in the Important CBM Areas

2.4.1. Development of CBM Industry in the UK

The utilization of CBM in the UK began earlier. As earlier as the 1970s, some coal enterprises started to use CBM extracted for power generation or supply it to neighboring residents. The surface exploitation of CBM was later. In the early 1990s, the government and enterprises had recognized that CBM is an important resource, and therefore the CBM exploration began to attract governmental attention. From 1991 to 1992, the government issued the CBM exploitation license to many enterprises allowing them to carry out the CBM surface exploration and development activities in the untouched coal fields. The first commercial CBM resources were verified in Airth area in 1993, and CBM produced here was used to generate electricity in 1996. Further evaluation works were conducted in other coal-bearing basins [29].

In the middle of the 1990s, the development of the CBM industry in the UK was confronted with some bottlenecks including imperfect laws and regulations of the CBM industry, low individual well production due to low permeability of the coal seams, low natural gas price and high drilling cost by using petroleum drilling equipment. Under these circumstances, CBM development investment risk was high, which had an negative influence on the investment passions of CBM enterprises [29].

In the late 1990s, the government realized that it should encourage the CBM development activities to increase the CBM proportion in energy supply and decrease the greenhouse gas emission, putting increasing stress on the energy security and environmental protection. In addition to issuing more licenses, the government also adopted some favorable policies which reduced the cost of CBM development through lowering tax. The government strengthened the restriction to the greenhouse gas emission to promote the CBM utilization rate. Besides, on the basis of the characteristics of the coal seams in the UK, the CBM enterprises adopted suitable technology in the CBM development. For example, it is the multi-branch horizontal well technology that solves the low individual well production due to low permeability of coal seams [29]. Under the promotion of these favorable conditions, the CBM industry in the UK developed rapidly.

It can be seen from the development of the CBM industry in the UK, the main reasons of the rapid development of the CBM industry conclude abundant CBM resources, encouragement policies from the government, strict requirements for environmental protection and suitable CBM development technology.

2.4.2. Development of CBM Industry in Germany

As early as in the 1970s, Germany started to utilize CBM extracted from the underground, but the utilization was only limited to the coal fields at a small scale. Electricity generation was the most important application of the CBM and its technology was rather full-fledged, but large-scaled development was impossible because of low profits resulted from low electricity price [30].

The year 2000 wais a milestone of the development of Germany CBM industry, and in this year the government published *Renewable Energy Law* and “Protective Plan of National Climate”. The former states that the eligible CBM electricity generation can obtain the government subsidy and the latter sets the limit of the greenhouse gas emission. Under these helpful environments, the CBM industry of Germany has started a rapid development period, and the number of the CBM enterprises and production bases has substantially grown [30].

Because CBM is mainly used for electricity generation, Germany pays much attention to the R&D of the CBM production equipments. Currently, some full-fledged technology and equipments are the modularization generating sets and the power and heat supplying thermal coupling BHKW equipment, which are used widely [30].

In addition to the utilization of the extracted CBM, Germany also pays attention to the development of CBM in abandoned mines. Nordrhein-Westfalen is one of coal production regions in Germany, and has lots of abandoned mines which contain abundant CBM resources. The Nordrhein-Westfalen government has made a special plan to utilize CBM from abandoned mines and invested in the CBM resource evaluation as well as the R&D of the technology concerned[30]. Therefore electricity generation using the CBM in abondoned mines has developed rapidly.

From the German experiences, the electricity generation using the CBM produced with the underground extraction method and from the abandoned mines is the main development way in Germany. It is the main reasons for the rapid development of the Germany CBM industry to subsidize the CBM electricity generation and develop the CBM electricity generation technology and equipments.

2.4.3. Development of CBM Industry in Canada

In the 1970s, Algas Resources carried out a drilling program in the foothills of Alberta, desorbing coal core samples and testing reservoir permeability and production flow rates. In 1981, the work was undertaken by Canadian Hunter Exploration to assess the CBM potential of the seams in the Elmworth area. Driven by San Juan Basin success in USA, early evaluation activities have been carried out in the late 1980s to early 1990s in Plains and Foothills of Alberta. Though the exploration and pilot test started very early in Canada, low gas price hindered CBM exploration for a long time.

Since 2000, CBM exploration has aroused the interest of industries in Canada due to the decline of reserves and production of conventional gas, increased demand for energy both in domestic and international markets and the increasing gas prices. The first commercial CBM project was successfully set up by MGV/Encana in Jan. 2002. From then on, the CBM exploration and exploitation started a rapid developing period in Canada. In 2003, Albert drilled 1,015 CBM wells totally and the CBM production was about $510×10^6$ m^3. 80% of the wells were operated in Horseshoe Canyon coal bed, 14% were in Mannville coal bed, and only 6% were in Ardley coal bed. Within the 1,015 wells, 780 wells were completed at coal beds, 80 wells were commingled producing wells of coal bed and sand bed, and the other 115 were recompleted existing natural gas wells. By the end of 2005, the total well number were 7,764 in Canada, and the wells in the Horseshoe coal bed were 7,377, 288 in Mannville coal bed, 62 in Ardley coal bed and 37 in Kootenay coal bed. By the end of 2006, the CBM daily production was $14×10^6$ m^3~$15×10^6$ m^3 and $5.1×10^6$ m^3~$5.5×10^6$ m^3 every year, among which about 60% was from Horseshoe Canyon coal bed, 30% from Horseshoe Canyon bed and the surrounding coal measure strata bed, 10% from Mannville coal bed and less than 1% was from Ardley coal bed. In 2005, the number of the CBM wells in Alberta added up to more than 7,700 with additional 2,943 new wells. By the 31th December 2006, Alberta's total number of CBM wells was 10,723 [3~5] (See Table 2.3).

Table 2.3 Total number of CBM wells in Alberta until 31 December 2006

Coal zone/formation	Total wells
Horseshoe Canyon and Belly River	9,762
Mannville	822
Ardley	100
Kootenay	39
Total	10,723

Source: 2006 Alberta Coalbed Methane Activity Summary and Well Locations, EUB, 2007.

Since the successful commercial development of the CBM in Horseshoe Canyon Coal by Canada, horizontal well technology for CBM development has become the first choice for many companies in the flied. The drilling technology is successfully applied in low-permeable Mannville Coal Bed and the maximum lateral segment is 2,500 m and maximum daily production is $56×10^3$ m^3.

According to the prediction of National Energy Committee, the CBM production will reach up to $14×10^9$ m^3 and $28×10^9$ m^3 by the year of 2010 and 2020 respectively. And the most optimistic prediction is $30×10^9$ m^3. If this prediction turns to be correct, the amount is 15% of the total gas production [5].

Following are the reasons for the rapid development and success of Canada CBM industry: a. Energy tension caused by natural gas price rising, which brings an opportunity for the CBM development; b. reduction of costs of CBM development by technology advancement in drilling multi-branch horizontal well and successive vitta fracture technology in accordance with the domestic characteristics of low metamorphosed coal.

2.4.4. Development of CBM Industry in the United States

The development of U.S. CBM industry experiences 3 stages. The pilot test stage from 1970s to the early 1980s, the rapid growth stage from the mid 1980s to the mid 1990s with production increase from $0.17×10^9$ m^3 in 1983 to $25×10^9$ m^3 in 1995, and the steady development stage from the mid 1990s to present with the production reaching $45×10^9$ m^3 in 2003 and $50×10^9$ m^3 in 2004 [8,29].

2.4.4.1. Pilot Test Stage

The United States Mineral Bureau arranged five-spot well pattern in the Oak Grove coal mine in 1971, and adopted the vertical well and fracturing technology to extract CBM. The aim was to test the CBM and evaluate its impacts on mining activities. Afterwards, the United States Mineral Bureau and United States Steel Corp cooperatively developed the CBM of this area and drilled 27 wells from 1977 to 1978 in the Oak Grove gas in the Black Warrior Basin, which represented the beginning of the U.S. CBM industry and also the modern CBM industry in the world. There was a close relationship between the CBM industry development in the Black Warrior Basin and coal mining. The commercial development of the San Juan Basin also began in the late 1970s, and it obtained industry gas flow in 1976 and started production in 1977. Differed from that in the Black Warrior Basin, the CBM development in the San Juan Basin had an intimate relationship with the oil industry. The 29th clause of Windfall Profit Act enacted in 1980 stated that 1m^3 CBM extracted from the wells drilled in 1979~1993 can get an allowance of 0.23 USD. Under the stimulation of this policy, oil companies represented by Amoco and Philips draw up active CBM exploration plans and devoted to the CBM development, which promoted the CBM industry development in the San Juan Basin. In the late 1980s, the U.S. had nearly finished the CBM resources investigation all over the nation and initially confirmed that the U.S. CBM resources are 2.02×10^{12} m^3~24.35×10^{12} m^3. At the same time, the U.S. recognized that CBM is absorbed on the surface of coal particles, so the pressure of the coal beds would decrease dramatically before producing in large amount, and the coal seams are water-bearing strata, so CBM is extracted out together with water. These became the basic development theories in the U.S., even in the world.

2.4.4.2. Rapid Growth Stage

In this period, the United States government invested 400×10^6 USD on the national wide research in reservoir formation and exploitation conditions. In accordance with this research, the United States realized that the producing capability of CBM (recoverability) depended on six factors including coal rank, gas content, permeability, hydrodynamic condition, structural setting, depositional system and formed the development theory that the CBM outputs following a process, that was “water drainage, decompression, desorption, divergency, infiltrating fluid”, which was the prerequisite to start and rapidly develop the CBM industry in the United States. At the same time, due to the influence of energy crisis, the government encouraged the exploration of unconventional energy by Windfall Profit Act to keep the steady supply of domestic energy. The CBM industry benefited the most from this policy. From the beginning of commercial production in the Black Warrior Basin and the San Juan Basin in 1981, the CBM production broke through 25×10^9 m^3 in 1995, which was a critical transition point for the development of the U.S. CBM industry. Hereafter, the CBM industry developed into a steady development stage.

2.4.4.3. Steady Development Stage

After the successful commercial development in the Black Warrior Basin and the San Juan Basin, new technology and new theories promoted the exploration and exploitation activities in other coal basins. From the 1990s, the amount of industrialized development basins increased continuously and the portion of their production increased gradually. The central Appalachian Basin became the third biggest gas producing basin. The Powder River Basin, the Uinta Basin and the Raton Basin became new area of industrialized development. The exploitation of gas reservoirs of low coal rank, low gas content, thick seam, high saturation and the application of technology such as cavern well completion and Pinnate Horizontal Directional Drilling were important reasons for the steady development of the CBM industry in the United States. The old areas such as the Black Warrior Basin and the San Juan Basin showed the tendency of stable production, high production and decreasing proportion in the total production. The new areas showed the tendency of fast development and increasing proportion.

2.4.5. Development of CBM Industry in Australia

In addition to the U.S., Australia is a country with successfully commercialized CBM development. Because the eastern coastal region has a huge natural gas market resulting from the dense population and advanced industry, the CBM activities in Australia are mainly concentrated in Queensland and New South Wales of the eastern coastal region. New South Wales is short of gas, but its gas consumption is the second in east Australia. The gas supply is mainly from Moonba Gas Field, 1,400 km away from Sydney, so the CBM market potential is better [29]. But due to the low-permeability and low-porosity characteristics of the coal seams in Australia, the individual well production is low [33], which restricts thedevelopment of the CBM industry.

The Australia CBM enterprises understand that the individual CBM well cost must be reduced to response to the low individual well production capacity. In recent ten years, with the gradually wide application of the new technology in Australia, CBM development investment and cost have been greatly reduced. The low-cost drilling technology of BHBP as well as the high efficient fracturing technology and low-cost drainage-extraction technique are the most successful technology and techniques. It was the technical progress that made the CBM development activities achieve great progress [4]. In 1998, Australia CBM production is 56×10^6 m^3 and increased to 1.18×10^9 m^3 in 2004. From 1996 to 2004, Australia had accumulative CBM production of 4.6×10^9 m^3. Queensland and New South Wales are the regions with the fastest-growing CBM production. In 2004, the CBM production in Queensland was about 927×10^6 m^3 and that in New South Wales was about 257×10^6 m^3.

Following are the reasons for the fast development and success of Canada CBM industry: a. insufficient supply and price increasement resulting from rising demand for natural gas; b. application of new technology to reduce the investment and cost of the CBM development; c. increased investment to detailed investigate the characteristics of the domestic coal seams and form more comprehensive detailed data laying a foundation for the CBM development and utilization; d. Australia is one of the "Kyoto Protocol" signed States and undertake an obligation of the greenhouse gas emission reduction, therefore, the government has made various measures to encourage the CBM development and utilization.

2.4.6. Development of CBM Industry in Russia

The activities of gas extraction in Russian coal mines started in the 1950s. The purpose is to ensure the security in coal mining by underground Ventilation and slim hole extraction on the ground. The extraction efficiency of the latter way can reach 30%~70% and the average concentration ratio of CH_4 was 30%~50%. The CBM development and utilization of Russia mainly concentrates in Kuzbass and Pechora. Kuzbass firstly started to reduce the CBM content of coal bed through extraction in 1951 and Pechora started commercial extraction in 1956, of which average extraction capacity is about 200×10^6 m^3 and utilized amount is 30×10^6 m^3~50×10^6 m^3 in recent years. In 1975, Vorkuta Coal Corporation started to extract CBM as fuel of steam boiler. In 2000, the Belovo coal mine of Kuzbass built the sole CBM utilizing equipment in Russia, which could compress 5 m^3~6 m^3 CBM and was used for generating electricity. The CBM emission amount of Kuzbass is about 1000×10^6 m^3~2000×10^6 m^3 per year, of which 100×10^6 m^3~200×10^6 m^3 is extracted out of the mine through pub-line. Now Russia is attempting to recycle and utilize the CBM in power generation, industry production and civil heating [29,31].

The rich natural gas resources and developed infrastructure can fully meet the domestic energy needs, which hampered the large scale development of the Russian CBM. But Russia has to join the "Kyoto Protocol", and undertakes the obligations to reducing greenhouse gas emissions, which will become the main impetus for the coal enterprises to pay attention to the CBM extraction technology and strengthen the CBM utilization [29,31].

2.5. Encouraging Policies of Main CBM Countries

2.5.1. Encouraging Policies of CBM Industry in UK

The British have carried out some encouraging activities for the CBM industry development, including: providing the flexible policy for issuing the mineral license to the CBM industry and making the tax policy preferable to the investors in the CBM industry. Due to the recognition that CBM is a valuable clean energy, the British government began to issue the CBM exploitation licenses to more enterprises in order to increase the investment in the CBM industry. CBM development is facing the same competitiveness as the conventional petroleum and gas development, and the British government has identified the CBM industry as a “eligible industry” making the investors in the CBM industry enjoy the tax cutting in “*Enterprise Investment Scheme*”. If invested in the CBM industry, 20% of the investment can be recovered by income tax relief. Besides, the “*Enterprise Investment Scheme*” regulates that at least during the first 5 years’ investment can the investors enjoy the preference, which encourage the long-term investment in the CBM industry [29].

2.5.2. Encouraging Policies of CBM Industry in the United States

The United States is the most successful country in promoting the commercialization of CBM development, because firstly, it has favorable CBM resources conditions and secondly, it made encouraging policies granted, including the financial support for technical research and exploitation test, the Section 29 Tax Credit in Crude Oil Windfall Profit Tax Act, FERC 636 and some other policies about environment and investment [29,31].

2.5.2.1. Fiscal Support for Technique Research and Exploitation Test

CBM as a kind of new energy, its industry development needs advanced technique research and exploitation tests. In that period, the United States government provided sufficient fiscal support, and some government agencies represented by Department of Energy and Gas Research Institute, as well as some other relevant research institutes and technical consultant corporations, proceeded research and tests, including the evaluation and prediction of the national CBM resources, research on exploitation technology, exploitation tests, reservoir simulation of some main basins and so on. All of these activities promoted the fast development of the relevant theory guiding the CBM exploratory development, technology and personnel reparation for CBM exploration.

2.5.2.2. The Section 29 Tax Credit in Crude Oil Windfall Profit Tax Act

The Section 29 Tax Credit in Crude Oil Windfall Profit Tax Act is an important drive for the occurrence and development of the United States CBM industry. Following is the introduction to its background, content and features.

1) Background of the Section 29 Tax Credit in Crude Oil Windfall Profit Tax Act

Throughout the 1970's, the price of most crude oil and refined petroleum products was regulated. In April 1979, President Carter announced that he intended to phase out oil price controls by September 30, 1981. The House Ways and Means Committee reported that the oil producers would obtain much greater profits, or "windfall profits" on the sale of petroleum fuels after elimination of price controls. The United States possesses vast reserves of many of the alternative energy resources and technologies available to develop these fuel sources, but the development of these alternative energy resources were always in stagnation state, either due to lack of research and testing and low market competitiveness of the development of these energy sources. The United States recognized that if the tax imposed on the “windfall profits" could be invested in supporting the alternative energy research and development, the effective development and utilization of these energy would be promoted, which would reduce energy imports and improve energy security. Under this circumstance, the purpose of the 29 Fuel Credit was to encourage production and use of these alternative resources by decreasing their production costs due to the low price of conventional fuels, and permitting them to become competitive in the market.

2) Content of the Section 29 Tax Credit in Crude Oil Windfall Profit Tax Act

The initial Section 29 Tax Credit in Crude Oil Windfall Profit Tax Act states that the expiration of the preferred tax policy for CBM is ten years from January 1, 1980 to the end of 1989. To ensure the rapid development of CBM industry, in 1988, the US government deferred the date to the end of 1990. Subsequently, the US government deferred the date to the end of 1992. That is to say, CBM could enjoy allowance if it is produced during January 1, 1980 and December 31, 1992. The rate of tax credit is relevant to the CBM production, oil price and the annual inflation rate and is subject to inflation rate and domestic oil price.

3) Characteristics of the Section 29 Tax Credit in Crude Oil Windfall Profit Tax Act

2.5.2.3. FERC Order 636

2.5.2.3. FERC Order 636

The U.S. Federal Energy Regulation Committee (FERC) recognized that the pipeline companies providing bundled natural gas and transportation service had the nature of anti-competition and restricted the benefits produced from the opening of access service and the decontrol of wellhead price. Therefore, in May 1992, the committee issued NO. 636 order, requiring the pipeline companies separate the sales of natural gas from transport service. And no matter whether shippers buy natural gas from them or natural sellers, they should non-discriminatorily provide comparable transportation service to all shippers. Through the efforts of the committee and the state in opening access and cancelling binding, market efficiency and competitiveness were enhanced and the total price of natural gas paid by consumers was reduced. Local gas supply companies started signing natural gas supply contracts in exploitation zone and additionally signed transport service contract. The FERC Order 636 has following influence on the CBM producers: CBM got access to more markets through the pipelines and the production flexibility was increased.

2.5.2.4. Credit Loan Policy

In March 1996, USEPA released *Sustentation Guidelines for CBM Project by Federal Government*, which stipulates the following departments should provide loan or assistance:

1) USDA assistance project

USDA Rural Corporation and Cooperative Development Bureau provide loan, loan guarantee and assistance to rural enterprises, mainly for new-technology-applied projects or the meager profit project in the countryside. Many high fiery collieries are located in rural areas, and they could obtain CBM project loan from local village credit department easily, and the loan limitation is 150,000 USD.

2) Assistant projects of U.S. Department of Commerce

The assistant objects of U.S. Department of Commerce are mostly those undeveloped areas. From 1992 to 1994, assistance fund provided by the department amounted to 46.1 million USD. CBM-powered electricity generating, pipeline-transported gas marketing or residence gas consumption projects all have the qualification to apply for this assistance.

3) Small Business Administration loan programs

The U.S. Small Business Administration (SBA) operates both a loan fund and a new program, called CAPLines, which may offer financial assistance to CBM projects. The loan program assists small businesses engaged in energy technology and energy efficiency. The SBA works with a designated financial institution to guarantee such loans if certain requirements are met. CAPLines provides federally guaranteed revolving lines of credit up to 750,000 USD or 75 percent of the loan amount, whichever is less, to small businesses. Coal mine methane recycle projects are commonly attributed to energy saving project, and especially CBM purification, methanol production or gas-powered car are projects with priority.

Many other agencies and organizations may provide assistance for CBM projects, including EPA and Department of Energy. In addition, under the policy orientation of the US government, many private financial institutions and banks are willing to provide financial support for CBM exploitation.

2.5.3. Incentive Policy for CBM Industry in Australia

The encouraging activities from the Australian government to the CBM industry include: issuing regulation to protect the legitimate rights of the investors in the CBM industry; the substantially increasing investment in natural gas pipelines through the privatization of natural gas pipelines to provide CBM industry with more improved natural gas pipe network; enacting mandatory measures to ensure the CBM development and utilization [29].

1) Mineral management of CBM

In 1997, the Australian Queensland Government issued a series of requirements for the mineral management of CBM. For instance, the CBM exploitation and ownership are protected by law; the investors are given access to the regions with existing oil production and coal mining, and try to avoid license conflict through vertical division of the mining rights.

2) Privatization of natural gas pipelines

Since 1993, Australia has been gradually privatizing natural gas pipeline, which has attracted enormous investment in the natural gas pipeline construction. Continuously improved natural gas pipeline networks meet the need of the CBM trasnportation.

3) Mandatory development and utilization measures of CBM

The Australian Government also attached great importance to guiding the CBM industry development. The government requires the mandatory standard for gas content in the coal mining, and only when the methane content is reduced under this standard through methane extraction in advance can the coal enterprises obtain the rights to explore coal; some local government regulate the mandatory percentage of the CBM electricity in the total electricity production to promote the enterprises to generate electricity with CBM.

2.6. Experiences and Lessons from Development of Overseas CBM Industry

1) Abundant resources are substantial foundation for CBM industry development

After the U.S. took the lead in the successful surface extraction of CBM, CBM began to be seen as a kind of valuable resource by the world. Taken as an industry, the quantity of CBM resources is the critical factor for CBM industry development, and only the rich CBM resources can support the development of large-scaled commercial development and utilization, and finally efficiently foster the CBM industry. The United States, Canada and Australia are the countries with the largest CBM resources in the world.

2) Growing demand for natural gas secures a reliable market for CBM industry development

Because of the same major components of CBM and natural gas, the industries of CBM and conventional natural gas have aimed at the same market. At present the world's oil supply is relatively insufficient, oil prices are high. Furthermore, many countries in the world increasingly pay more attention to environmental protection, and this attention has resulted in the rapid increase in the demand for natural gas by residents, power generation industry and processing industry and the natural gas supply and demand gap is continuously widening. In the main gas production countries, the consumption of natural gas in the energy consumption structure is larger, and the markets for CBM exist, which is the main reason to stimulate the development of coal-bed methane and promote the CBM industry development.

3) Developed infrastructure and open access policy is an important condition for CBM industry development

It is necessary for large-scale CBM commercial development to use the pipeline for transportation, and due to the characteristics of low production and long payback period, it is more economically favorable to use the existing natural gas pipelines than to built new pipeline. Some countries, such as the United States and Canada, have well-developed natural gas storage and transportation facilities and utilization infrastructure. Developed distribution system affords convenient condition for the commercial production of CBM. In addition, the implementation of open access policy make the CBM producers enjoy a fair and reasonable terms for the use of natural gas infrastructure. In the United States, after its complete reform of the natural gas market, natural gas infrastructure operators are no longer engaged in the sale business of natural gas, and only under the supervision of the government, they provide gas producers or users with fair and reasonable infrastructure services. The results of the reform make CBM producers at a lower cost set up its own coal-bed methane distribution network.

4) Theoretical research and technical development is key support for CBM industry

CBM exploitation is a technology-intensive industry, and the CBM accumulation and production process differ from that of natural gas, and therefore, it is essential to do research and develop the suitable theories and technology for CBM production.

As for the main CBM production countries, the U.S. has discovered advanced technologies for drilling, completion, stimulation and production as well as full-fledged development theories aiming at the middle-low coal rank. Thus the U.S. has become the most successful CBM production country in the world. Based on the characteristics of low density, low pressure, low permeability, Canada has invented the coiled tubing drilling and the emission of nitrogen foam fracturing techniques and learned the multi-branch horizontal well technology from the United States to improve the CBM production and achieve the rapid development of the coal-bed methane industry. With the high gas content and low permeability characteristics in its coal seams considered, Australia has developed the short radius drilling technology and close radius drilling technology to improve the coal seam permeability, thus increasing the CBM production. Benefited from technical innovation, Australian CBM industry has developed rapidly.

5) Encouraging policies are driving forces for CBM industry development

Compared with that of conventional natural gas, CBM industry has its unique characteristics, such as low individual well production, long production cycle, high initial investment and high investment risks, and therefore, in the early development of CBM industry, it is unable to compete with conventional natural gas. In order to encourage enterprises to invest in coal-bed methane industry, the government needs to implement encouraging policies to increase profits and reduce risks. Encouraging policies include financial support for the research in the basic theory and critical technology as well as exploration work, tax relief, direct financial subsidies, etc. The support for theoretical and technological study can contribute to the CBM development theory and technology suitable for geological features to increase production and reduce costs. The fiscal support for the CBM development can increase the CBM market competitiveness, and improve economic feasibility of the CBM development projects. These encouraging policies play an important role in attracting investments in the CBM industry.

6) Rational laws and regulations are basic factor for CBM industry development

CBM and coal have the characteristic of co-existence, and there may be conflicts for their licenses issued, which needs to be effectively coordinated. In addition, as natural gas industry, the CBM industry also faces issues as mineral right, exploration, development, pipeline transportation, distribution, infrastructure construction, environmental protection, and so on. Only through legislation to ensure the stakeholders in the CBM industry clearly aware of their rights and obligations, can an effective system of regulation on the CBM industry and the protection of legitimate rights be realized. The main CBM production countries regulate the CBM exploration and development and implement the encouraging polices by promulgation of laws and regulations. All laws and regulations can be implemented with good effects.

7) Increasingly stringent environmental requirements are driving force for CBM industry development

The main component of CBM is CH_4, which is a greenhouse gas. The greenhouse effect of CH_4 is about 20 times more of that of CO_2. In addition, methane is destructive to ozone by seven times more than CO_2. the "*United Nations Framework Convention on Climate Change*" adopted in New York in 9 May 1992 states that the developed countries undertake responsibility and obligations of reducing greenhouse gas emissions. The direct emission of the methane into the air from coal mining is one of main ways of the methane emissions, and all CBM production countries including developed countries put forward strict requirements for CBM emission. The "*<United Nations Framework Convention on Climate Change> Kyoto Protocol*" adopted in Kyoto Japan in 11 December 1997 further defines the emission reduction obligations of the developed countries, which enhances the interest of the major CBM production countries fin CBM development and utilization.

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Chapter 3 CBM Resources in China

The very important basic work in the feasibility study on CBM production in China is to give a comprehensive analysis of the CBM resources in the country. In this chapter, the CBM resources in China will be discussed first. A comprehensive description is presented about the total amount of the CBM resources and its distribution. The geological characteristics of the CBM resources are also analyzed. Based on the results of these descriptions and analysis, some comprehensive evaluations of the target CBM resource belts and preditions have been made and, consequently, the resource condition ranking is also given.

3.1. The Regionalization of CBM Resources in China

The reasonable regionalization of CBM resources is the base for searching opportunities of CBM exploration and development and for guiding the concrete performance of CBM exploration and exploitation. In the following, the basic principles for the regionalization of CBM resources in China will be discussed and the corresponding regionalization plans will be given.

3.1.1. The Basis Principles of CBM Resources Regionalization

1) Using related research results for reference

According to the geological functions in respect to the coal accumulation course and according to the actual situations of the coal resources distribution in China, Chinese coal geologists have studied the regionalization of coal resources and put forward some different views about the regionalization of coal fields (See Table 3.1).

Table 3.1 some typical regionalization plans of coal accumulation fields

Expert(s) or team / year	Regionalization plan	Regionalization purposes
The National Administration Bureau of Coalfield Geology /1986	coal accumulating region, coal-bearing region, prediction region	resource prediction and evaluation
Qian Dadu, etc / 1996	coal accumulating region, coal-bearing region, coal field, coal prospect	resource prediction and evaluation
The National Administration Bureau of Coalfield Geology /1997	coal accumulating region, coal-bearing region, coal field，exploration region or predicting region	resource prediction and evaluation
The National Administration Bureau of Coalfield Geology /2001	coal accumulating region, coal accumulating basin	analysis of coal accumulation process and rules

Source: Zhao Jinghong, Shi Baohong, 2005.

After nearly 20 years' geological research and exploration practice, substantial progress has been made in CBM geological research area, and a set of CBM accumulation geological theories and regional selection evaluation technologies have been formed. A brief summary of the major views on the regionalizatio of CBM geological units is listed in the Table 3.2 [3].

2) The main factors considered in the regionalization

Based on the related research results above, the following factors should be taken into account in regionalization of CBM resources in China.

a. SN-NNE trending tectonic zones divided by stratiggraphic changes in deep strata. According to the regional geophysical reference materials and data, there appears apparently stepped zones in the deep strata from the west to the east across China. These can be summarized as 3 main SN-NNE trending tectonic zones divided by stratiggraphic changes in deep strata, such as Helan-Longmenshan zone, Daxinganlin-Wulingshan zone and the east continent edge zone in the sequence from the west to the east. This zone-dividing phenomenon has caused extensive and profound influences on the regionalization and exploration of CBM resources in China. We will, therefore, use these zones as the base for the first-rank regionalization of CBM resources.

b. The boundaries of geotectonic subdivision. On the basis of SN trending zones, we will divide the zones further into CBM-richit regions by determining some boundary lines in near east-west directions according to the geological plate boundaies and the boundaries between stable regions (landmass) and active regions (fold zones). The main boundary lines selected are the boundary between Tarim-North China plate and Tianshan-Chifeng active region, the boundary between Tarim-North China plate and South China plate, and the boundary between Yangtze plate and Songpan-Ganzi active region. These boundaries play important controlling role in the formation and distribution of coalfields in China and, thus, can be used as the base for the second-rank regionalization.

Table 3.2 Summary of the major regionalization plans of CBM accumulation units

Experts / year	Regionalization plans	Regionalization purpose
U.S.A/1995	Region, Province, Basin, Play, Cell	Resource evaluation
Zhao Qingbo/1996	Region, block, prospect	Exploration regional selection evaluation
Ye Janping/1998	CBM accumulation region, belt, prospect	Resource evaluation
Zhang Jianbo/2000	Region，basin, block	Resource evaluation
Liu Honglin/2001	CBM accumulation region, belt, field	Resource evaluation
Zhang Xinmin/2002	CBM region, gas-bearing area, belt, field	Resource evaluation
Zhao Qinbo/2002	Region, belt, prospect, block evaluation	Exploration and regional selection evaluation

Source: Zhao Jinghong, 2005.

c. Regional tectonic formation and coal-accumulation characters. There are 4 important coal-accumulating periods in China, namely Carboniferous-Permian, late Permian，early and middle Jurassic and early Cretaceous. The coal beds formed in the 4 different periods have specific major accumulating ranges respectively and have experienced different later tectonic deformations. These characters can be used for the third-rank regionalization.

d. CBM-bearing property. The CBM-bearing property here refers to the content of CBM, the thickness of the coal bed and the area of the reserve in a region. Due to low content of CBM, small area size, or complicate tectonic structure, some coal beds in remote districts will not be taken into account in the regionalization of CBM resources.

e. Administrative area factors. The administrative area factors should also be considered in the resource regionalization. That will be convenient for regionalization nominating and be easy for statistics and decision-making about CBM resources.

3.1.2 The Regionalization Plan of CBM Resources in China

Base on the regionalization principles described above and according to the actual resource distribution as well as the situation of the actual exploration and development activities, a regionalization plan is selected in the research, according to which the CBM resources in China are divided into different regions of four ranks: CBM zones, CBM-bearing regions, CBM-bearing belts and CBM fields (See Figure 3.1).

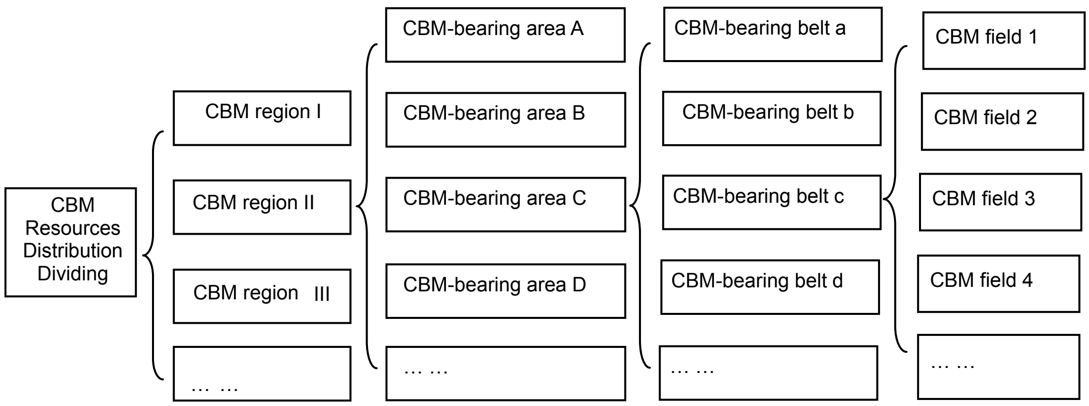

Figure 3.1 Regionalization plans of CBM resources

According to this regionalization plan, we divide the national CBM resources into 4 zones, 10 regions, 56 belts and more than 85 fields (prospects) (See Table 3.3~Table 3.5).

Table 3.3 Regionalization of CBM resources of China (Eastern Zone)

Zone	Region	Belt	Prospect
East Zone	Heilongjiang, Jilin and Liaoning I (Northeast China)	Sanjiang-Mulinghe I_{01}	Shuangya mountain, Boli, Hegang, Jixi
		Yanbian I_{02}	Yanbian
		Hunjiang-Liaoyang I_{03}	Hongyang
		Fushun I_{04}	Fushun
		West Liaoning I_{05}	Fuxin, Tiefa
		East Songliao Basin I_{06}	Huhehu Depression, Huolinhe
		Southwest Songliao Basin I_{07}	
	Heibei, Shandong, Heinan and Anhui II (North and east China)	Eastern of north Hebei II_{01}	
		Beijing-Tangshan II_{02}	Daqing mountain, Xuanxia, Xinglong, Jiyu, Kailuan, Liujiang, Lingshan
		East Taihang Mountain II_{03}	Fengfeng, Jiaozuo, Lincheng, Anyang-Hebi
		Central Hebei Plain II_{04}	Dacheng
		North Henan and Northwest Shandong II_{05}	North Henan
		West Henan II_{08}	West Henan
		East Henan II_{09}	East Henan
		Xuhuai II_{10}	Huaibei
		Huainan II_{11}	Huainan
	South china III	Southeast Hubei and north Jiangxi III_{01}	North Jiangxi
		Lower Yangtze river III_{02}	
		Jiangsu, Zhejiang and Anhui III_{03}	
		Jiangxi and Zhejiang III_{04}	East Jiangxi
		central Hunan III_{06}	Lianshao
		South Hunan III_{07}	South Hunan
		North and central Guangxi III_{08}	Hongmao, Luocheng, Heshan

Table 3.4 Regionalization of CBM resources of China (Central Zone)

Zone	Region	Belt	Prospect
Central Zone	East Inner Mongolia IV	Unclassified	
	Shanxi, Shaanxi, and Inner Mongolia V (north and northwest China)	Western of north Hebei V_{01}	
		Daning V_{02}	Ningwu
		Qinshui V_{03}	Yangquan, Heshun-Zhuoquan, Luan, Jingcheng, Huodong, Taiyuan Xishan
		Huoxi V_{04}	Huozhou
		Eastern margin of the Ordos Basin V_{05}	Xiangning, Wubao, Liulin, Fugu, north Sanjiao
		Weibei V_{06}	Hancheng, Chenghe, Pubai, Tongchuan
		North Ordos Basin V_{07}	North Ordos Basin
		West Ordos Basin V_{08}	West Ordos Basin
		Zhuo-He V_{09}	Shizuishan, Zhuozishan, Rujigou, Weizhou, Maliantan, Hulusitai
		North Shaanxi V_{10}	North Shaanxi
		Huanglong V_{11}	Huanglong
	Yunnan, Guizhou, Sichuan, and Chongqing VI (southwest China)	Huayingshan VI_{01}	Helianci, Zhongshan, north Huayingshan, central Huayingshan, Tianfu, Zhongliangshan, Libixia, Xishan, Nantong, Nanwu, Songzao
		Yongrong VI_{02}	Luoguanshan, Qingshanling, Zhenxiong，Guxu，Gufuoshan, Furong, Julian,
		Yalian VI_{03}	Emei Mountain
		South Sichuan and north Guizhou VI_{04}	Northwest Guizhou, North Guizhou
		Guiyang VI_{05}	Guiyang
		Liupanshui VI_{06}	Guishan, Enhong, Xuanwei, Liupanshui, Xingyi, Zhina
		Dukou Chuxiong VI_{07}	Dukou

Table 3.5 Regionalization of CBM resources of China
(Western Zone and Offshore Zone)

Zone	Region	Belt	Prospect
West Zone	North Xinjiang VII	Turpan-Hami VII_{01}	Ewirgol
		Santang-Naomaohu VII_{02}	Santang-Naomaohu
		South Junggar VII_{03}	Baiyanghe
		East Junggar VII_{04}	
		North Junggar VII_{05}	North Junggar
		Ili VII_{06}	Ili
		Yourdusi VII_{07}	Yourdusi
		Yanqi VII_{08}	Yanqi
	South Xinjiang-Gansu Tsinghai VIII	Inner Mongolia, Gansu and Ningxia $VIII_{01}$	
		Xining-Lanzhou $VIII_{02}$	
		Hexi Corridor $VIII_{03}$	
		Nouth Qaidam $VIII_{04}$	
		East Tarim $VIII_{05}$	
	Yunnan-Tibet IX	No data VIIII	
Offshore Zone	Taiwan X	Taiwan X	

3.2. CBM Resources and Distribution in China

3.2.1. Total Amount of CBM Resources in China

Since the 1980s, many experts in related research organizations and companies in China have done much work for the CBM sources calculations and predictions. Although some differences are concluded from the results, the fact that there exist huge amount of CBM resources in China is evident according to all the predictions (see Table 3.6).

According to the latest evaluation of petroleum resources by the Ministry of Land and Resources of China, the amount of CBM resources with buried depth less than 2,000 m is about $34.5×10^{12}$ m^3. And the resources can be developed and utilized during the coming 20 years under the current technology. The CBM resources of good quality with buried depth from 300 m to 1,500 m will be given priority for exploration and development in the near future. Besides, about CBM resources of $50×10^{12}$ m^3 with buried depth from 2000 m~4000 m might also be explored and utilized in the future with the progress of technology.

According to the estimation methods of CBM recovery efficiency in mature areas in the U.S.A., CBM resources recovery coefficient is generally ranged from 10% to 50% in China, with the mean value of 30%. Accordingly, the total amounts of the recoverable CBM reserves in China are estimated to be over 10×10^{12} m^3.

Table 3.6 Previous Evaluations of CBM Resources in China

Organizations or Experts	Amount ($10^{12} m^3$)	Areas evaluated
Jiaozuo Mining Institute (1987)	31.92	All minable coal seams in China
Li Minchao ect. (1990)	32.15	All minable coal seams in China
Petroleum Geology Institute of Ministry (1990)	10.6~25.23	
Xi'an subsidiary court (1991)	30-35	Ex lignite, Tibet, Guangdong, Fujian, Taiwan and C1, P1 coal bed
The China National State-owned Coal Mines Corp. (1992)	24.75	Recoverable CBM of all minable coal seams in China
Duan Junhu (1992)	36.30	
Guan Deshi (1992)	25~50	
Zhang Xinmin ect. (1995)	32.68	Ex lignite, Tibet, Guangdong, Fujian, Taiwan and C1, P1 coal bed
Ye Jianpin ect. (1998)	14.34	Ex areas that gas-bearing of shallow CBM less than 4 m^3/t
China United Coalbed Methane Corp. (2000)	31.46	Ex lignite, Tibet, Guangdong, Fujian, Taiwan and P1 coal bed
Wang Hongyan ect. (2005)	27.3	
Ministry of Land and Resources (2005)	35	

Sources: Zhang Xinmin, 2002; Wang Hongyan, 2005.

3.2.2. Distribution of CBM Resources in China

1) The distribution of CBM resources over the different CBM-zones

The amount of CBM resources with buried depth of 300 m~2,000 m in China is about 35×10^{12} m^3 as mentioned above. The CBM resources distributions over the 3 main zones are listed in Table 3.7 (The situation of the Offshore Zone is omitted here duo to lack of data). The table shows clearly that the CBM resources in the mainland are mainly concentrated in the Central zone and the West Zone.

Table 3.7 CBM resource distribution over the different CBM-zones

Zone	Resources ($10^9 m^3$)	Percentage (%)	Coal rank	Main geology age
Central zone	20,077.61	63.81	middle, high	C, P
			low	J_{1-2}
West zone	7,990.18	25.40	low, middle	J_{1-2}
East zone	3,393.46	10.7	middle, low	K_1
Total	3,1461.25	100.0	-	-

Source: Zhang Xinmin, 2002.

2) The distribution of CBM resources over the different CBM-regions

Among the 10 CBM regions, the Region of Shanxi-Shaanxi-Inner Mongolia is the largest one in amount of CBM resources, with about 17.25×10^{12} cubic meters' CBM resources, that is 54.83% of the total amount of national CBM resources. The second largest region is North Xinjiang, with about 6.88×10^{12} cubic meters' CBM resources, 21.86% of the total amount. The South China Region is the smalles region, with only 0.16×10^{12} cubic meters' CBM resources, only 0.50% of the national resources.

3) The distribution of CBM resources over the different CBM belts and geological periods

There are great differences in resource amount in different CBM belts. The two largest CBM belts with richest resources are the North Ordos Basin Belt and Qinshui Belt. The Yanbian Belt is, in contrast, the smallest, with about 13.25×10^{9} cubic meters' CBM resources, only about 0.02% of that of north Ordos Basin Belt. Among the 56 CBM belts in China, there are 9 CBM belts with more than 1×10^{12} cubic meters' CBM resources (See Table 3.8), all located in Central Zone (the Region of Shanxi-Shaanxi-Inner Mongolia and the Region of Yunnan-Guizhou-Sichuan) and the West Zone (the North Xinjiang region).

Table 3.8 Conditions of the 9 largest regions with over 1×10^{12} m^3 CBM Resources

CBM belts	Coal-forming age	Resources amount ($10^9 m^3$)	Resources density ($10^9 m^3/km^2$)
North Ordos Basin	C-P, J_{1-2}	5,582.561	0.109
Qinshui Basin	C-P	5,515.777	0.201
Turban-Hami Basin	J_{1-2}	2,625.898	0.151
East margin of Ordos	C-P	1,996.227	0.122
Liupanshui	P_2	1,509.434	0.170
East Hui river	J_{1-2}	1,453.217	0.074
West Ordos Basin	J_{1-2}	1,273.206	0.063
Yili	J_{1-2}	1,219.191	0.121
South Sichuan and north Guizhou	P_2	1,038.179	0.033

Source: Zhang Xinmin, 2002.

Table 3.8 shows the distribution of the CBM resources over different geological periods of coal formation. About 90% of CBM resources located in the coal beds were formed in early and middle Jurassic, Carboniferous and Carboniferous-Permian periods. Among all these coal beds, the coal beds formed in early and middle Jurassic periods are the largest coal bed group with respect to CBM resource amount, and that is about 46% of the total amount in China. The second largest group of coal beds are those formed in Carboniferous-Permian, about 43.52% of the total amount in China. These coal-beds are thickest and their distributions are stable. Quality, ranks and permeability of coal are fit for CBM formation, accumulation and exploitation.

4) The distribution of CBM resources over different buried depths

According to experience in CBM exploitation in other countries, the CBM wells should not be too deep; otherwise the CBM production will lose its economic value. Under current technical and economic conditions in China, the CBM resources with buried depth from 300 m to 1500 m are appropriate for exploration in the near future. The CBM resources with buried depth from 1500 m to 2000 m can be taken as the succeeded resources in the future. The CBM resources distribution over different buried depth is showed in Table 3.9. The table shows that the CBM resources recoverable in near future with buried depth of 300 m~1500 m account for 60% of the total amount.

Table 3.9 Distribution of CBM Resource over different buried depth

Buried depth (m)	Resources amount ($10^{12}m^3$)	Percentage (%)
300~1,500	19.08	60.65
1,500~2,000	12.38	39.35
Total	31.46	100

Source: Zhang Xinmin, 2002.

5) The distribution of CBM resources over different coal ranks

The distribution of CBM resources over different coal ranks is summarized in Table 3.10.

Table 3.10 Distribution of CBM resources over different coal ranks

Coal rank	Long Flame Coal	Non and weakly-caking Coal	Gas coal	Fat coal	Coking Coal	Lean coal	Poor coal	Anthra -cite	Total
Resources ($10^{12}m^3$)	6.65	8.78	3.01	1.55	0.86	0.83	0.88	2.44	25.00
Percentage (%)	26.6	35.2	12.1	6.2	3.3	3.3	3.5	9.8	

Source: Zhang Xinmin, 2002.

3.3. The Geological Conditions and Characteristics of CBM Resources in China

3.3.1. Geological Analysis of China's CBM Reservoirs

Through summarizing the experiences and the results from the practice and research of China's CBM exploration in the past years, a preliminary theory frame of CBM geology in China has been established. Under the guidance of this theory frame, expected results have been achieved in China's CBM exploration [5]. The main aspects of the theory frame are as follows:

1) There are 4 types of CBM reservoirs, namely reservoir sealed off from underground pressure, reservoir blocked by confined water, reservoir sealed off by roof-water stratum with network-shaped micro-percolation, and structural trap reservoir. Generally, there is less methane but with much water in exploitation of reservoirs sealed off by roof-water stratum with network-shaped micro-percolation, while less water is found but the methane is hard to be desorbed off in exploitation of structural trap reservoirs. The reservoirs sealed off from underground pressure or the reservoirs blocked by confined water have high methane saturation degree and can provide favorable conditions for methane enrichment and for high methane yielding.

2) From boundary to abdomen area of a coal basin, there exist sequently 4 types of belts with different contributing factors: methane weathering belt, bio-degradation belt, saturated adsorption belt and low-desorption belt. The contents of CBM in a methane weathering belt are mainly N_2 and CO_2. In a bio-degradation belt, the CBM $\delta^{13}C_1$ is light, with value from -50‰ to -65‰. There can be less methane but with much water in exploitation of such a belt. A low-desorption belt is usually buried deeply. Its CBM $\delta^{13}C_1$ is heavy, with value of less than -45‰. In exploitation of such a belt, low production rate will often met because of its poor physical properties and little content of desorptable methane. The most favorable CBM exploration targets are saturated adsorption belts. Its CBM $\delta^{13}C_1$ is from -30‰ to -50‰. Such belts are usually of high methane content and high methane saturation degree and, therefore, can provide favorable conditions for methane enrichment and for high methane production.

3) CBM reservoirs are often impacted by 5 types of reformation functions: hydrodynamic scrubbing, coal stratum mineralization, tectonic coal crumbling, diagenetic compaction and differential accumulation caused by tectonic deformation. The hydrodynamic scrubbing can make the original reservoir open up to the surface, so that methane content could lose and the production rate of a CBM well might be low because of its low methane saturation degree. With the impact of coal stratum mineralization, coal seams would be filled with calcite veins

and, thus, the physical properties of the reservoir would become poorer. The tectonic coal crumbling could, under the fuction from tectonic stress, change the structure of coal particles and turn the coal into powder or mylonitic texture, leading to lower CBM well production rate. By diagenetic compaction, the physical properties of coal seams would become worse with the increasement of buried depth, resulting in very low CBM well productivity. The differential accumulation caused by tectonic deformation could usually uplift the basin and reduce the buried depth of the coal bed. During this course, more secondary huggers would be created in the coal seam and the physical properties of the coal would be improved. If there is an adequate methane supply from the down strata and the roof-stratum can form a condition as confined water block, the coal bed can become the favorable tectonic region with high methane content, high methane saturation degree, good physical properties, and better conditions for methane enrichment and for highCBM production [6].

3.3.2. The overall Geological Characters of CBM Resources in China

The geological structures of China's coalfields are complex. Some coal basins have undergone much strong reconstruction in the later stage, resulting in diverse tectonic structures. The preservation conditions for coal and CBM are, generally, simple in the large and medium-sized basins, such as Ordos Basin, but more complicated in small basins and in some medium-sized basins.

1) Coal-bearing basins and their formation conditions

The coal basins of China are densely distributed in plates or belts with relatively stable tectonic activities such as the Tarim-North China Plate, the South China plate and Junggar-Xing'an active belt. These coal basins are formed mainly in the Carboniferous - Permian, the Late Triassic - Early Cretaceous and Tertiary [8]. According to locations in geotectonic structures and considering the sedimentation features, they can be divided into two types: within-plate craton type and continental rift or depression type. The CBM reservoir formation processes in the coal basins will be controlled by the following conditions: The ancient climate, ancient plants, ancient geography , ancient tectonic and sedimentation environment altogether determine the coal formation, distribution and quality; Tectonic deformation directly controls the overall sealed conditions of coal basin,and affects the buried depth and the infiltration of the coal reservoir; The metamorphic grade of coal-measure rocks affects the amount of methane generation on one hand, and affects the infiltration of coal-measure rocks on the other hand; The sealing gland layers and hydrodynamic conditions determine the preservation states of CBM reservoirs.

2) The features of China's CBM resources

a. Rich, scattered but also concentrated in distribution

The amount of China’s CBM resources with buried depths of less than 2000 m is up to 300×10^{12} m^3~350×10^{12} m^3, about 13% of the total amount of the world's CBM resources, as the second largest country (merely one behind Russia). The CBM resources are widely scattered distributed in different coal basins overall in China. The resources with superiority and potential for exploitation are, however, densely distributed in the middle and eastern of North China (62%). This area is a “blind region” of conventional gas generation, but a clean energy’s consumption-booming region. Exploiting the CBM resources in this area has practical significance for relieving the contradictions between supply of and demand for natural gas, reducing strain on coal transportation and decreasing the heavy dependence on coal in the area [8].

b. Strong inhomogeneity in the tectonic structures of the reseroirs, with relative superiority in the basins in North China

The multicycle characteristics and complexity of the crustal movement in China have resulted in the homogeneity of the coal seams and CBM reseroirs in different regions and different geochrons. Especially, because of different tectonic backgrounds for coal formation, different intensities and scopes of the tectonic damage in latter stages, and different influences from area’s thermal history, strong inhomogeneity in regional geology and in microstructure components has formed in the CBM reservoirs. But the tectonic basements in North China are relatively stable. The tectonic actions in latter stage were relatively simple in the middle part of North China and, especially, the rapid regional thermo-metamorphic processes in latter

Yanshan stage made the coal reservoirs in this area become relatively favorable for exploitation.

c. High-rank coal and low-rank coal are dominant in China and CBM can be exploited from high-rank coal

In China, the CBM exists mainly in the high-rank and low-rank coal, and about 85.56% of the total amount of China's CBM resources exist in high-rank coal seams. According to the CBM theories developed in the USA, the middle-rank coal eservoirs are the most favorable CBM prospects for exploitation. China's exploitation practices show, however, that the high-rank coal reservoirs, which are denied by the American CBM theories, are the most active exploration areas and some breakthroughs have been made in practical CBM exploration. The CBM resources of low-rank coal account for the largest proportion in total amount of CBM resources in China, but they are supposed to be too difficult to exploit according to the existing theory and technology.

d. Coal structures being severely damaged, many coal seams withf low permeability, low pressure and low saturation degree

Because of severel tectonic damages after coal formation, many coal seam structures have been disrupted, especially in the CBM-bearing areas in the south part of China. The coal basins formed in the Caledonian fold belt or in the transitional zones suffered further multiple destructions in the Indo-Chinese movement, the Yanshan movement and the Himalayan movement, resulting in the formation of large areas of tectonic coal. Low permeability, low pressure, and low saturation are the notable features of China's CBM reservoirs, and these cause great difficulty for CBM exploitation.

3) The geological and reservoir characteristics of CBM-rich regions

According to related research results [9,10], there are 10 CBM-rich regions. The amount of CBM resources in these 10 CBM-rich regions is about one-third of the total amount in China. These regions are different from each other in metamorphic grades, in controlling factors and conditions of CBM resources. They have their own characteristics also in CBM content and in many other features (See Table 3.11).

3.3.3. Descriptions of the Geological Characteristics of the Major CBM Regions

We will give brief introductions to the following seven major CBM regions.

1) Heilongjiang-Jilin-Liaoning region

Heilongjiang-Jilin-Liaoning region ranges from the country's boundary line in the north and east part to the east section of the Yinshan-Yanshan fold belt in the south part and to the Daxinganling tectonic belt in the west part. The coal strata in this region were formed primarily in Cretaceous and Tertiary system, and secondly in Carboniferous-Permian system. The Early Cretaceous coal basins are well developed and the CBM-bearing properties are relatively better. In the Tertiary system, only Fushun basin has higher rank coals such as long flame coal and gas coal with good CBM-bearing properties, while all other basins contain only lignitous coal with low CBM content and, therefore, are excluded from evaluation this time. The coal beds formed in Carboniferous-Permian system exist only in the south part of the CBM region, where coal seams are stable and the CBM-bearing properties are relatively better. The CBM resources distribute mainly in Heilongjiang province and Liaoning province. In these two provinces, there are some rich CBM belts such as Sanjiang-Mulinghe belt, Hunjiang-Liaoyang belt and West Liaoning belt.

This region is also the place where the earliest CBM resources exploration activities were carried out. The CBM resource exploration activities are mainly concentrated in the areas around Shenyang City of Liaoning province in the south part of the region. Worse results have been met from the exploration practice in Hegang basin in the north part of the region. The CBM exploitation activities are merely mine methane extractions. Evident economical and social benefits have been achieved from these activities in Fushun, Tiefa, Hegang, Jixi coal fields.

2) Hebei-Shandong-Henan-Anhui region

Hebei-Shandong-Henan-Anhui region belongs to the North China Coal-accumulation Area. It is located in the east side of Taihang Mountain, approximately east part of the North China Landmass, ranging from Qinling tectonic belt in the west, to the Jiaolu fault belt in the east, from the southern boundary of Liaoning-Jilin-Heilongjiang region in the north, to the east section of Qinling-Dabieshan fold belt in the south. The coal strata are mainly Carboniferous-Permian system, with a little part in Middle-Lower Jurassic Petroleum system. The coal strata in the Carboniferous-Permian system in this region spread widely over a large sedimentation area, with stable coal seams and good coal-bearing properties. As there exist many districts with favorable exploration and exploitation prospects, the CBM exploitation activities are very active in this ragion, and some notable progresses have been achieved in Kailuan, Dacheng, Huaibei and Huainan coalfields.

Table 3.11 stratigraphic features of the CBM regions in China

CBM abundant region	Coal geo-chron	$\frac{\text{no. of seams}}{\text{thickness(m)}}$	CBM content (m^3/t)	Saturation (%)	Volume of CBM ($10^9 m^3$)	Direct caprock lithology/ Thickness(m)	Basement types
Central of Ordos Basin	J	$\frac{3\sim5}{10\sim20}$	2~8	65~80	1,070	Mudstone/ 4~8	Stable platform District
Eastern part of the Ordos Basin	C-P	$\frac{2}{10\sim35}$	12~25	75~90	5,926.2	Mudstone/ 5~22	Stable platform District
Qinshui Basin	C-P	$\frac{2}{9\sim15}$	13~34	81~100	3,966.8	Limestone/ 1~12	Stable platform District
Yuxi syncline	C-P	$\frac{3}{10\sim12}$	17~25	70~95	572.7	Mudstone/ 12~28	Platform and fold transition zone
Luxi - Puyang slope belt	C-P	$\frac{2\sim3}{10\sim14}$	15~20	80~85	175.5	Mudstone/ 3~9	Platform and fold transition zone
Jizhong - Jidong slope belt	C-P	$\frac{3\sim5}{12\sim22}$	12~23	60~80	225.7	Mudstone/ 2~13	Stable platform District
Huainan - Huaibei synclinor e	C-P	$\frac{3\sim5}{15\sim26}$	11~22	77~92	400	Mudstone/ 3~5	Platform and fold transition zone
Liupansh ui coalfield	P2	$\frac{5\sim7}{20\sim45}$	17~32	73~96	1,706.4	Mudstone/ 12~16	Stable platform District
Tianshan piedmont	J	$\frac{10\sim20}{45\sim150}$	2~6	62~85	208.6	Sand interbedded Mudstone/ 38~190	intermediary massif District
Songliao - Liaoxi	J3-K1	$\frac{3}{22\sim220}$	3~7	55~75	32.4	Sand interbedded Mudstone/ 14~170	intermediary massif District

Source: Zhang Xinmin, 2002.

3) South China region

The South China region is located in the vast land ranging from Qinling-Dabieshan fold belt in the north and from Wuling Mountain tectonic belt in the west, including the most part of

Southeast and South China. The coal strata in this region are mainly in the Late Permian system. Due to the influence of tectonic movements of Catharina and Neocathaysian systems, only little part of Late Permian coalfields are preserved well, with relatively stable coal seams and good CBM-bearing properties. The CBM resources in this region are concentrated mainly in Jiangxi province and Hunan province, with abundant CBM resources especially in Pingle and Xiangzhong belts. Some CBM exploration activities have been carried out in Fengcheng and Lengshuijiang coalfields, achieving good results in Fengcheng coalfield.

4) Shanxi-Shaanxi-Inner Mongolia region

Shanxi-Shaanxi-inner Mongolia region (region V) is one of the richest CBM resources areas in China. It is located in the west side of the Taihang Mountain in the North China area, ranging from Helanshan-Liupanshan fault in the west, to the west boundary of Hebei- Shandong-Henan-Anhui region in the east, from the west section of Yinshan–Yanshan fold in the north, to the west section of Qinling–Dabieshan fold in the south. The coal strata in this region are mainly in Carboniferous Permian and Middle-Lower Jurassic systems, with good coal-bearing properties and large stable spreading coal seams. In view of the CBM-bearing properties, the Qinshui and Hosie belts are the best ones, Shanbei and Huanglong belts are relatively worse, and all other belts are in middle quality.

This region is the most active area where many CBM exploration and exploitation projects have been done. Especially in Jincheng, Tunliu, Liulin and Linxing, some successful pilot tests have been made, showing very good development prospects.

5) Yunnan-Guizhou-Sichuan-Chongqing region

Yunnan-Guizhou-Sichuan-Chongqing region (region VI) is located in the west part of south China coal area. It is ranged from Longmenshan-Yanlaoshan fault belt in the west, to the west boundary of South China CBM region in the east, from the south boundary of Shanxi- Shaanxi-Inner Mongolia CBM region in the north, to the country's boundary in the south. The coal strata in this region were formed mainly in Permo-Carboniferous system, with wide sedimentation area, stable coal seams, good coal-bearing property and CBM-bearing property. The CBM resource in Liupanshui belt is the most abundant and its resources abundance in this belt is also the highest. Following the Liupanshui belt, the Huayinghan belt, Yongrong belt, Chuannan-Qianbei belt and Guiyang belt are also rich in CBM resources. Little CBM resources have been found in Yale belt and Dukou-Chuxiong belt. In this belt, only the Panzhihua Mine district in Baoding coalfield is has rich CBM resources in coal strata of Triassic system, but the scale is small and the coal seam thickness changes greatly.

Subject to the terrain conditions, the CBM exploration activities in this region are not so much and so quick as those in other CBM regions. But the methane extraction in coal mines is very successful in this region. The extraction activities in Songzao, Nantong, and Zhongliangshan coalfields around Chongqing city are very famous in China. In addition, successful results of the extraction activities have been achieved also in Furong in Sichuan province, and liuxiao, Panjiang, Shuicheng, lindong in Guizhou province.

6) North Xinjiang region

The North Xinjiang region (region VII) is located in Tianshan Fold and the area north to this fold. In this region, there are many Middle Jurassic coal basins such as Junggar, Turpan–Hami, Yili and so on. The coal seams are stable and thick, with good coal-bearing property. However, the coal grade is low (mostly long-flame coal), and the CBM-bearing property is relatively poor. Only in partial districts, due to the superimposed effect by abnormal high ancient geothermal field, the coal grade becomes higher, and then CBM-bearing property becomes better.

7) South Xinjiang-Gansu-Qinghai region

Southern Xinjiang-Gansu-Qinghai region (region VIII) is located in the area at the south side of Tianshan, in northwest coal-accumulated area. It ranges from the west section of Tianshan -Yinshan fold in the north, to the west section of Kunlun-Qinling fold in the south, from the country boundary line in the west, to the west boundary of Shanxi-Shaanxi-Inner Mongolia CBM region in the east. There are developed Middle Jurassic and Carboniferous-Permian coal basins in this region. The early-middle Jurassic coal seams here are low in coal grade, mostly kennel coal, with poor CBM-bearing property. The Carboniferous-Permian coal seams in this region are higher in coal grade, with limitation in distribution. This region is poor in CBM resources and no CBM exploration and exploitation activities in the area.

3.3.4. Description of Geological Characteristics of the Major CBM Belts in China

Much research work has been done on the 56 CBM belts. Several geological parameters of the belts are collected and summarized here such as coal-formation age, coal rank, buried depth, CBM saturation, CBM content, resource density and volume of CBM. The detailed parameter information and data of all the 56 CBM belts are listed in Annexed Table 1 at the end of this report. For the purposes of illustration, the parameter data and information of some main CBM belts are given as follows (See Table 3.12).

Table 3.12 Geological parameters of some main CBM belts

	CBM raegion	Coal-forming age	Main coal rank	Buried depth (m)	CBM saturation (%)	CBM content(m^3/t)	Resource density ($10^6m^3/km^2$)	Volume of CBM (10^9m^3)
1	Sanjiang-Mulinghe I_{01}	K1		<1,000		3.46	24	224.35
		K1	FM/JM	1,000~1,500		8.28		
				1,500~2,000		9.98		
2	Fushun I_{04}	R3		<1,000		9.23	7	4.46
		R3	CY	1,000~1,500		9.23		
				1,500~2,000	85	8.26		
3	Qinshui V_{03}	C-P		<1,000		16.13	201	5,515.78
		C-P	SM/PM/WY	1,000~1,500	95	21.39		
				1,500~2,000	95	22.06		
4	Huoxi V_{04}	C-P		<1,000		16.13	183	735.55
		C-P	FM/JM/SM	1,000~1,500	95	21.39		
				1,500~2,000	95	22.06		
5	Weibei V_{06}	C-P		<1,000		7.87	94	701.1
		C-P	SM/PM/WY	1,000~1,500	85	18.31		
				1,500~2,000	85	18.84		
	…	…	…	…	…	…	…	…

3.4. Ranking and Optimized Evaluation of CBM Belts in China

In this section, optimized evaluations and ranking studies will be given on the 56 CBM belts described in the regionalization section. The basic process is: selecting evaluation parameters according to the geological conditions and the purpose of evaluation, calculating and processing the related parameter information and data by applying primarily statistic calculations and data processing methods, determining the index weights accordint to the suggestions of the experts, and then, giving the comprehensive evaluation and ranking results by means of the weighted average methods.

3.4.1. Selection of the Evaluation Criteria and the Methods for Dada Processing

The ranking and comprehensive evaluation will be carried out according to the quantitative analysis principle and on the basis of the most significant criteria which can directly reflect the quality of CBM resources. In the process of ranking analysis, the index values will be firstly processed according to the requirement and, then, appropriate methods will be selected for dimensionless calculations. The weights of the indices are determined mainly according to experts' suggestions, because the experts play very important roles in evaluations of the quality of CBM resources.

According to principles and the ranking process mentioned above, three indices, namely resources density, CBM resource volume and CBM density, are considered as the most significant indices reflecting directly the qulity and conditions of CBM resources. They are, thus, selected as the basis in the evaluation and ranking analysis.

Generally, Indices can be divided into positive indices, inverse indices and neutral indices according to their significance directions. In the evaluation process, inverse indices and neutral indices must be firstly specially processed into the corresponding data with positive direction. The selected indices may have different dimensions, so dimensionless processing calculations are needed. Of course, the calculations for positive derection and for dimensionless can be conducted together at the same time. In this report, three types of processing functions have been designed respectively for the three different types of indices (positive, inverse and neutral indices) and the designed functions can be use to carry out the calculations for positive derection and for dimensionless simultaneously.

For positive indices, only dimensionless processing is needed. The processing function is designed as follows:

$$u_{ij} = \frac{x_{ij}}{\max_i\{x_{ij}\}}, \quad i = 1,2,\cdots,n;\ j = 1,2,\cdots,m,$$

Where, x_{ij} is the real value of the corresponding index, and u_{ij} is the dimensionless value of the index (These valuables have the the same meanings in the following functions).

For inverse indices, both positive processing and dimensionless calculations are required. The processing function is designed as follows:

$$u_{ij} = \begin{cases} \dfrac{\min_i\{x_{ij}\}}{x_{ij}} & x_{ij} \neq 0 \\ 1 & x_{ij} = 0 \end{cases}, \quad i = 1,2,\cdots,n;\ j = 1,2,\cdots,m \quad .$$

Like inverse indices, both positive processing and Dimensionless calculations are needed for neutral indices. The processing function is designed as follows:

$$u_{ij} = \begin{cases} \dfrac{\max_i\{x_{ij}\} - x_{ij}}{\max_i\{x_{ij}\} - v_j} & x_{ij} > v_j \\ \dfrac{x_{ij} - \min_i\{x_{ij}\}}{v_j - \min_i\{x_{ij}\}} & x_{ij} < v_j \\ 1 & x_{ij} = v_j \end{cases}, \quad i = 1,2,\cdots,n;\ j = 1,2,\cdots,m,$$

Where, v_j is the medium (or ideal value) of the neutral index.

Sometimes we should consider the lowest requirements in some indices in the process of resources evaluation, the so called Threshold Bound method is applied for selecting the target regions. One method which can be used here is to select the target regions satisfying with the screening requirements directly according to the Threshold Bound values. Another method can be described as follows: first the upper limits and the lower limits will be determined for all the indices. When the actual value of some index is greater than the upper limit of the index, it will be taken ato be equivalent to the maximum value or the ideal value, but when the actual value of some index is less than the lower limit of the index, it will be taken to be equivalent to the minimum value or the worst value. The main characteristic of this method is that the optimal value or the worst value is distributed over a definite interval, instead of merely a single value.

For positive indices, the processing function is designed as follows:

$$u_{ij} = \begin{cases} 1, & (x_{ij} \geq u_j) \\ 0, & (x_{ij} \leq d_j) \\ \dfrac{x_{ij} - d_j}{u_j - d_j}, & (d_j < x_{ij} < u_j) \end{cases} \quad , \ i = 1,2,\cdots,n; \ j = 1,2,\cdots,m \, ,$$

Where, u_j is the upper limit, d_j is the lower limit.

For inverse indices, the processing function is designed as follows:

$$u_{ij} = \begin{cases} 0, & (x_{ij} \geq u_j) \\ 1, & (x_{ij} \leq d_j) \\ \dfrac{u_j - x_{ij}}{u_j - d_j}, & (d_j < x_{ij} < u_j) \end{cases} \quad , \ i = 1,2,\cdots,n; \ j = 1,2,\cdots,m \, .$$

For neutral indices, the processing function is designed as follows:

$$u_{ij} = \begin{cases} 0, & (x_{ij} \geq u_j; \ x_{ij} \leq d_j) \\ 1, & (zd_j \leq x_{ij} \leq zu_j) \\ \dfrac{x_{ij} - d_j}{zd_j - d_j}, & (d_j < x_{ij} < zd_j) \\ \dfrac{u_j - x_{ij}}{u_j - zu_j}, & (zu_j < x_{ij} < u_j) \end{cases} \quad , \ i = 1,2,\cdots,n; \ j = 1,2,\cdots,m \, ,$$

Where, zd_j is the upper limit of the median interval (the ideal value interval), zu_j is the lower limit of the median interval.

3.4.2. The Results of Comprehensive Evaluation and Ranking of the CBM Belts

All the selected indices for ranking analysis are positive indices, so we can directly use dimensionless processing method mentioned above in the calculations. The weights of the indices are determined according to the experts' suggestions (See Table 3.13). Through the calculations of comprehensive evaluation, the scores of every CBM belt are obtained and the belt rankings are given according to the scores in the high-low order (See Table 3.14).

The first 20 CBM belts, according to the ranking, are Qinshui, Ordos Basin Northern, Huoxi, Liupanshui, Turpan-Hami, Zhuo-He, Ordos Basin East Edge, Henan Eastern, Taihangshan East Foot, Weibei, Henan Western, Yili, Mid-Heibei Plain, Daning, Hunan Southern, Anhui Southern, Tarim Easernt, Beijing-Tangshan, Sichuan-Southern & Guizhou Northern and

Mid-Hunan.

Table 3.13 Weights of the indices for ranking of CBM regions from the experts

Evaluation indices	Resource density	Volume of CBM	Volume of gas
Weights	0.3	0.4	0.3

Table 3.14 Rankings of CBM belts

CBM belts	Resource density	Volume of CBM	CBM content	Total scores	Rank
Qinshui V_{03}	1.000	0.988	0.956	0.982	1
North Ordos Basin V_{07}	0.542	1.000	0.287	0.649	2
Huoxi V_{04}	0.910	0.132	0.956	0.613	3
Liupanshui VI_{06}	0.846	0.270	0.519	0.518	4
Turpan-Hami VII_{01}	0.751	0.470	0.284	0.499	5
Zhuo-He V_{09}	0.891	0.140	0.474	0.466	6
The eastern margin of the Ordos Basin V_{05}	0.607	0.358	0.467	0.465	7
East Henan II_{09}	0.572	0.072	0.721	0.417	8
East Taihang Mountain II_{03}	0.587	0.079	0.669	0.409	9
Weibei V_{06}	0.468	0.126	0.722	0.407	10
West Henan II_{08}	0.652	0.100	0.523	0.392	11
Ili VII_{06}	0.602	0.218	0.307	0.360	12
Central Hebei Plain II_{04}	0.572	0.077	0.520	0.358	13
Daning V_{02}	0.687	0.048	0.412	0.349	14
South Hunan III_{07}	0.104	0.007	1.000	0.334	15
Huainan II_{11}	0.667	0.062	0.358	0.332	16
East Tarim $VIII_{05}$	0.667	0.093	0.300	0.327	17
Beijing-Tangshang II_{02}	0.572	0.020	0.396	0.298	18
South Sichuan and north Guizhou VI_{04}	0.164	0.186	0.561	0.292	19
central Hunan III_{06}	0.149	0.008	0.782	0.282	20
West Ordos Basin V_{08}	0.313	0.228	0.246	0.259	21
Hunjiang-Liaoyang I_{03}	0.219	0.013	0.553	0.237	22
Southeast Hubei and north Jiangxi III_{01}	0.030	0.001	0.728	0.228	23
Guiyang VI_{05}	0.085	0.017	0.604	0.213	24
Pingle III_{05}	0.050	0.005	0.615	0.201	25
Huayingshan VI_{01}	0.124	0.011	0.530	0.201	26
Hexi Corridor $VIII_{03}$	0.234	0.034	0.346	0.188	27

Continue

South Junggar VII_{03}	0.264	0.062	0.271	0.185	28
Yalian VI_{03}	0.030	0.004	0.579	0.184	29
Inner Mongolia, Gansu and Ningxia $VIII_{01}$	0.284	0.016	0.291	0.179	30
Lower Yangtze river III_{02}	0.055	0.002	0.518	0.173	31
Yanqi VII_{08}	0.149	0.062	0.334	0.170	32
North Shaanxi V_{10}	0.164	0.067	0.303	0.167	33
Yongrong VI_{02}	0.119	0.014	0.394	0.160	34
Sanjiang-Mulinghe I_{01}	0.119	0.040	0.349	0.156	35
Santang-Naomaohu VII_{02}	0.154	0.060	0.285	0.156	36
North Junggar VII_{05}	0.114	0.090	0.279	0.154	37
Jiangxi and Zhejiang III_{04}	0.025	0.001	0.484	0.153	38
North Henan and northwest Shandong II_{05}	0.129	0.045	0.310	0.150	39
Huanglong V_{11}	0.030	0.003	0.458	0.147	40
Fushun I_{04}	0.035	0.001	0.444	0.144	41
Nouth Qaidam $VIII_{04}$	0.164	0.010	0.292	0.141	42
North and central Guangxi III_{08}	0.075	0.002	0.391	0.141	43
Xuhuai II_{10}	0.025	0.061	0.358	0.139	44
Jiangxi and Zhejiang III_{04}	0.050	0.003	0.376	0.129	45
West Liaoning I_{05}	0.075	0.007	0.311	0.119	46
Xining-Lanzhou $VIII_{02}$	0.090	0.002	0.291	0.115	47
Yourdusi VII_{07}	0.050	0.009	0.304	0.110	48
Eastern of north Hebei II_{01}	0.060	0.001	0.296	0.107	49
Dukou Chuxiong VI_{07}	0.050	0.005	0.285	0.102	50
Western of north Hebei V_{01}	0.045	0.002	0.260	0.092	51
East Song Liao basin I_{06}	0.010	0.001	0.177	0.056	52
Southwest Song Liao basin I_{07}	0.010	0.000	0.167	0.053	53
Yanbian I_{02}	0.010	0.000	0.167	0.053	54
No data VIIII	0.000	0.000	0.000	0.000	55
Taiwan X	0.000	0.000	0.000	0.000	56

Besides, we can also carry out the ranking process by taking the Threshold Bound values of the three indices into account. Only those belts will be selected and ranked, of which the resource density value is more than 50×10^6 m^3/km^2, the CBM content value is more than 8 m^3/t, and the resource volume is more than 50×10^9 m^3. The results are showed in Table 3.15. We can see that the results are basically equivalent to the previous evaluation and ranking.

According to selection principles together with the comprehensive evaluation and ranking results, priority will be given to the development of the following CBM belts: Qinshui, Liupanshui, Ordos Basin East Edge, Zhuo-He, Huoxi, Weibei, Taihangshan East Foot, Mid-Heibei Plain, Daning, Anhui Southern, Henan Eastern, Turpan-Hami, Sichuan-Southern & Guizhou Northern, Liaoning Western and Hunan Southern.Resource condition and the ranking analysis prove that the best resources are basically distributed in the Hebei-Shandong-Henan-Anhui CBM region and the Shanxi-Shaanxi-Inner Mongolia CBM region.

Table 3.15 Ranking of the key CBM belts by considering the threshold bound values

No.	CBM belts	Resource density ($10^9m^3/km^2$)	Volume of CBM (10^9m^3)	CBM content (m^3/t)	Total scores	Original ranking
1	Qinshui V_{03}	0.201	5515.777	19.86	0.982	1
2	North Ordos Basin V_{07}	0.109	5582.561	5.9625	0.649	2
3	Huoxi V_{04}	0.183	735.545	19.86	0.613	3
4	Liupanshui VI_{06}	0.17	1509.434	10.78	0.518	4
5	Turpan-Hami VII_{01}	0.151	2625.898	5.9	0.499	5
6	Zhuo-He V_{09}	0.179	782.913	9.85	0.466	6
7	Eastern margin of the Ordos Basin V_{05}	0.122	1996.227	9.69	0.465	7
8	East Henan II_{09}	0.115	400.234	14.97	0.417	8
9	East Taihang Mountain II_{03}	0.118	442.809	13.89	0.409	9
10	Weibei V_{06}	0.094	701.102	15	0.407	10
11	West Henan II_{08}	0.131	559.841	10.85	0.392	11
12	Ili VII_{06}	0.121	1219.191	6.38	0.360	12
13	Central Hebei Plain II_{04}	0.115	430.802	10.79	0.358	13
14	Daning V_{02}	0.138	265.303	8.55	0.349	14
15	Huainan II_{11}	0.134	348.572	7.43	0.332	16
16	East Tarim $VIII_{05}$	0.134	521.765	6.227	0.327	17
17	Beijing-Tangshan II_{02}	0.115	109.213	8.23	0.298	18
18	West Ordos Basin V_{08}	0.063	1273.206	5.1	0.259	21
19	South Junggar VII_{03}	0.053	347.249	5.637	0.185	28
20	Inner Mongolia, Gansu and Ningxia $VIII_{01}$	0.057	90.381	6.05	0.179	30

3.5 Ranking and Comprehensive Evaluation of the Chinese CBM Prospects

In the evaluation process, the indices will be selected according to the geological conditions and evaluation purposes together with the parameter lists of CBM prospects. And the appropriate methods will be used to standardize processing of the indices dada. The index weights will be determined on the basis of suggestions of the related experts.

3.5.1. The Basic Criteria and Indices for Evaluation and Ranking of CBM Prospects

Some domestic organizations in the business have put forward several different evaluation criteria for evaluation and ranking of CBM prospects. The key contents can be summarized as follows.

1) The coal seams should be thick enough and extensively distributed, with the single seam thickness greater than 0.6 m and the total thickness greater than 10 m.

2) The thermal evolution maturity is moderate (0.7%＜Ro＜1.7%, middle grade coals: gas coal, fat coal, coking coal, lean coal).

3) The buried depth of coal bed is moderate in a range of 300 m~1500 m.

4) The coal natural fracture system is prosperous and the permeability should be higher than 1×10^{-3} μm^2.

5) The hydrogeological conditions are satisfied. The reseroirs should be located in the confined water districts or the detention water districts and easy to decompress.

6) Basin slope or syncline area with moderate buried depth can be selected as the exploration region. The relatively low crustal stress area under the high crustal stress background cab be selected as the important area in the exploration region.

7) Future CBM resources amount should be bigger than 10×10^9 m^3. The coal seams are widely distributed and the main coal seams are stable.

8) The CBM content should be higher than 8 m^3/t. The content of coal petrography should be generally more than 70%.

9) The cleat density in coal seams should be bigger than 500 s/m. The primary penetrance measured by the single injection or pressure-reducing method should be bigger than 0.5×10^{-3} μm^2.

10) The seams' depth should be at best in the range from 500 m to 1500 m. The strong water cycle methane weathered area and the low permeable coal beds with low desorption rate should be avoided.

11) Regional magmatic thermal metamorphisic area could be the favorable exploration region, because the reservoir is generally of high rank anthracite, high CBM content and prosperous cleat.

12) The water pressure closed CBM reservoirs in Artesian Aquifer and the pressure closed high-pressured CBM reseroirs can be selected as the best exploration targets.

CBM exploitation is firstly influenced by the geological characters of the CBM resources and the geological characters include the coal rank, buried depth, adsorption properties, permeability, CBM content and so on. The exploitation technology conditions include mainly the well network arrangement, well drilling and completion technology, drainage technology and strengthening stimulation measures. At the resources evalution stage, the main influence factor is the ground conditions. The economic factors include mainly the investment, cost, taxes, fees, operation cost and CBM price. Resource evalution takes potential market as a factor, and the other economic factors will be considered in production capacity calculations and in economic evaluations.

Based on the above mentionede criteria and the basic analysis, the main parameters which affect CBM reserves and the principal aspects of reservoir development should be considered in the evaluation and ranking of the CBM prospects. These parameters include 4 kinds of factors such as the geological background, the reservoir factor, the resource factor and the basic development factor. The following indices are selected as the concrete indices: coal rank, buried depth, permeability, coal seam thickness, CBM-bearing area, CBM content, ground condition and market demand etc. Some related indices are explained as follows.

1) Coal rank and CBM-bearing area

The total CBM amount is determined by the degree of coal seam development. The higher the coal rank is and the thicker the coal seams are and larger the distribution area of the coal stratum is, the more the total amount of the CBM resources. As the evaluation criterion for different evolution degrees of a CBM reservoir, the index coal rank will be divided into high, middle and low coal rank as follows:

Low coal rank: Ro≤0.7%, including lignite, long flame coal;

Middle coal rank: 0.7%＜Ro≤1.7%，including gas coal, rich coal, coking coal, lean coal

High coal rank: 1.7%＜Ro≤4.0%, including poor coal, anthracite coal Ⅲ.

Coking coal and lean coal are the most favorable coal rank in the assessment of CBM prospects. In quantitative processing, we assign the value 3 to coking coal and lean coal in the middle coal rank, the value 2 to gas coal, rich coal, poor coal, and anthracite coal Ⅲ, and the value 1 to lignite and long flame coal.

2) Buried depth

In consideration of the different degrees of defficulties in the CBM exploitation, we assign the value 1 to the coal strata with buried depth less than 500 m or more than 2000 m, the value 3 to the coal strata with buried depth from 500 m to 1000 m, the value 4 to the coal strata with buried depth from 1000 m to 1500 m, and the value 2 to the coal strata with buried depth from 1500 m to 2000 m.

3) CBM content and Permeability

No matter how complicated the geological factors are, the CBM content and permeability of a coal reservoir are the most important factors. The former is the embodiment of CBM enrichment, and the latter is the prerequisite of CBM high production rate. All other factors play different control functions to these two factors, and reflect their influences through the concrete characteristics of these two foctors. Generally, a CBM reservoir can be regarded as the favorable exploration prospect, if the CBM content is more than 10 m^3/t and permeability is more than 2×10^{-3} μm^2. The statistical data indicate that the permeability is in the value range of 0.5×10^{-3} μm^2 ~ 5.0×10^{-3} μm^2 in the coal seams of CBM wells with high production rates in China. The impacts of CBM content on the production rate are evident. A CBM prospect with CBM content of more than 15 m^3/t can be predicted as a high production rate area. In comparison, a prospect with CBM content in value of 8 m^3/t ~ 15 m^3/t can be considered as a middle production rate area, and those with CBM content less than 8m^3/ t can be regarded as low or even no-production areas.

4) Thickness

Being thick enough is the prerequisite for CBM enrichment and for high productivity. According to the international experiences and the domestic practices, it is very possible to have a high productivity if the single-layer coal thickness is more than 3 m. For resources potentiality point of view, the total thickness of all the coal seams should be more than 10 m.

5) Ground condition

The ground condition influences the ground investment costs and the degree of difficulty in CBM exploitation. In quantitative analysis, we assign value 8 to the plain condition, value 6 to the hilly condition, value 4 to mountainous condition and value 1 to gully condition.

6) Market demand

Because the CBM development and utilization in a region is similar to those of the natural gas, we can use natural gas consumption situations to estimate the CBM market demand. In our research processes, the local CBM demands are calculated on the basis of comprehensive consideration of the citys' conditions, populations, terrains, transportation and the local pipeline infrastructure. The detailed calculations and the results are described in Chapter 5 of this report.

3.5.2. The Indices and Data Processing for Ranking of the Main CBM Prospects

We have done comprehensive analysis on the CBM prospects and collected the information and parameters data of 85 CBM prospects. The parameters include coal strata, coal rank, buried depth, permeability, coal seam pressure, porosity, coal seam thickness, CBM-bearing area size, CBM saturation, CBM content, etc. The detailed data is described in Annexed Table 2 at the end of the report. For illustration of results, some CBM prospects are selected here and in Table 3.16. Surface condition will be decided based on geographical position and the outcomes of market demand estimate are shown in Annexed table 5.

Table 3.16 Geological parameters of CBM prospects in China

CBM prospect	CBM bearing area (km^2)	Coal rank	Buried depth (m)	Coal bed pressure (MPa)	Thickness (m)	Permeability ($10^{-3}\mu m^2$)	CBM content (m^3/t)	Porosity (%)
Daqingshan	32.6	QM-SM	500~1500	5~15	10	0.07	16.4	5.65
Xuanxia	298	CY-JM	500~1500	5~10	10	0.07	15	4.9
Xinglong	68.2	QM-WM	500~1500	5~22	8.65	0.07	15	5.16
Sanjiaobei	1921	QM-FM	500~1200	4	8~17.5	0.15~11.6	8.7	4.6
Hancheng	4310	PM-WY	300~900	7.6~8.5	8.93	1.93~3.01	11.8	1.67~4.81
Fuxin	600	CY-QM	800	6.7	60~80	0.3~0.6	4.9	0.2~0.4
Tiefa	513	CY-QM	850	4	30~40	0.1~1.51	6.5	0.1~0.4

The scores of coal rank, buried depth and ground condition are given according to the principles mentioned above. According to experts' suggestions, all the indices can be classified into 4 different classes of groups according to their weights in evaluation. Because permeability and CBM content are the most major influence factors, they are listed in the first group. Coal seam thickness and CBM-bearing area have important influence on the total CBM amount, and thus they are listed in the second goup. In comparison, market demand and coal rank are listed in the third group and the other indices are listed in the fourth group. The weights of the indices are determined according to the group classification (See Table 3.17).

Table 3.17 Index weights for ranking of CBM prospects

Index classes of Significance	Very important indices		Important indices		More important indices		common indices	
Concrete indices	Permeability	Gas content	Coal seam thickness(m)	Gas-bearing area (km^2)	Market demand	Coal rank	ground condition	Buried depth (m)
weights	0.2	0.2	0.15	0.15	0.1	0.1	0.05	0.05

3.5.3. Comprehensive Evaluation and Ranking of CBM Prospects in China

The weighted average calculation method is used here for comprehensive evaluation and ranking of CBM Prospects in China. The dimensionless data results are listed in Table 3.18.

Table 3.18 Ranking of the Chinese CBM prospects

No.	CBM prospect	Coal rank	Buried depth	Permeability	Coal thickness	CBM area	CBM content	Topography	Market demand	Total score
1	Sanjiaobei	1.000	0.875	1.000	0.433	0.036	0.470	0.563	0.199	0.583
2	Zhuluoxi	0.500	0.750	0.667	0.267	1.000	0.432	0.625	0.045	0.572
3	Hancheng	0.667	0.750	0.833	0.298	0.080	0.638	0.563	0.429	0.547
4	Luan	0.833	1.000	0.328	0.500	0.061	0.730	0.625	0.111	0.533
5	Daqingshan	1.000	0.875	0.012	0.333	0.001	0.886	1.000	0.529	0.512
6	Zhongliang-shan	1.000	0.750	0.004	0.364	0.005	0.919	0.750	0.688	0.507
7	Jincheng	0.667	1.000	0.417	0.283	0.025	0.762	0.563	0.111	0.503
8	Xiangning	0.833	0.875	1.000	0.340	0.089	0.270	0.563	0.107	0.501
9	Liupanshui	0.833	0.625	0.005	0.667	0.085	0.811	0.500	0.145	0.497
10	Wubao	1.000	0.875	0.333	0.333	0.039	0.649	0.563	0.084	0.489
11	Shizuishan	1.000	0.750	0.667	0.450	0.001	0.330	0.875	0.118	0.481
12	Tianfu	1.000	0.750	0.002	0.265	0.004	0.843	0.750	0.688	0.469
13	Songzao	0.667	0.750	0.050	0.267	0.005	0.924	0.688	0.688	0.467
14	Gufushan	0.833	0.750	0.002	0.133	0.008	0.957	0.688	0.712	0.464
15	Liujiang	0.833	0.750	0.042	0.333	0.001	0.811	0.813	0.101	0.463
16	Heshun-Zuoquan	0.833	1.000	0.167	0.433	0.086	0.655	0.375	0.140	0.460
17	Xinglong	0.833	0.875	0.012	0.288	0.001	0.811	0.875	0.410	0.460
18	Fengcheng	0.667	0.750	0.002	0.150	0.013	0.968	0.750	0.105	0.457
19	Xuanxia	0.667	0.875	0.012	0.333	0.006	0.811	0.938	0.529	0.454
20	Tiefa	0.500	0.500	0.017	0.667	0.010	0.811	0.563	0.046	0.451
21	Jiaozuo	0.667	0.875	0.493	0.213	0.014	0.546	0.813	0.133	0.448
22	Liulin	1.000	0.750	0.188	0.333	0.062	0.615	0.563	0.199	0.447
23	Nantong	0.833	0.750	0.075	0.167	0.003	0.811	0.750	0.688	0.442
24	Yangquan	0.667	1.000	0.033	0.433	0.101	0.719	0.375	0.140	0.438
25	Hulusitai	0.833	0.750	0.083	0.827	0.001	0.432	0.875	0.118	0.435
26	Hongyang	0.833	0.500	0.027	0.333	0.003	0.757	0.875	0.293	0.435
27	Zuozishan	1.000	0.750	0.667	0.293	0.001	0.303	0.563	0.036	0.434
28	Ningwu	1.000	0.875	0.333	0.633	0.016	0.324	0.563	0.192	0.433
29	Fugu	1.000	0.750	0.528	0.500	0.057	0.270	0.500	0.084	0.433
30	Xuanwu	1.000	0.625	0.046	0.601	0.157	0.524	0.375	0.150	0.430
31	Rujigou	0.667	0.750	0.050	0.363	0.000	0.724	0.875	0.118	0.430

Continue

No.	CBM prospect	Coal rank	Buried depth	Permeability	Coal thickness	CBM area	CBM content	Topography	Market demand	Total score
32	Kailuan	0.833	0.750	0.042	0.583	0.000	0.551	0.875	0.410	0.426
33	Enhong	1.000	0.625	0.046	0.601	0.013	0.497	0.875	0.150	0.425
34	Luoguan-shan	1.000	0.750	0.002	0.100	0.006	0.784	0.688	0.991	0.423
35	Pingxiang	0.833	0.750	0.045	0.083	0.000	0.811	0.688	0.136	0.420
36	Dacheng	0.833	1.000	0.025	0.633	0.062	0.432	0.938	0.512	0.419
37	Anyang-Hebi	0.833	0.625	0.008	0.183	0.011	0.778	0.750	0.142	0.416
38	Furong	0.667	0.750	0.012	0.150	0.017	0.827	0.563	0.089	0.408
39	Fuxin	0.500	0.500	0.050	1.000	0.011	0.432	0.563	0.041	0.395
40	Weizhou	0.833	0.750	0.500	0.150	0.011	0.314	0.875	0.122	0.383
41	Heshan	0.667	0.500	0.005	0.200	0.003	0.795	0.375	0.184	0.380
42	Lingshan	0.833	0.625	0.053	0.400	0.001	0.541	0.625	0.116	0.379
43	Lianshao	0.833	0.750	0.008	0.433	0.007	0.519	0.688	0.081	0.379
44	Xishan	0.833	0.750	0.002	0.217	0.003	0.622	0.750	0.803	0.378
45	Luocheng	0.667	0.500	0.005	0.200	0.001	0.757	0.563	0.089	0.378
46	Guishan	0.833	0.625	0.046	0.601	0.002	0.416	0.750	0.150	0.377
47	Huaying-shan middle piece	0.833	0.750	0.058	0.120	0.008	0.659	0.313	1.000	0.365
48	Zhina	0.667	0.625	0.005	0.267	0.081	0.649	0.375	0.145	0.364
49	Fengfeng	0.833	0.625	0.298	0.133	0.012	0.432	0.688	0.154	0.360
50	Nanwu	0.833	0.750	0.062	0.167	0.001	0.541	0.750	0.688	0.358
51	Libixia	0.833	0.750	0.002	0.317	0.004	0.508	0.688	0.803	0.356
52	Aiweiergou	0.833	0.625	0.083	0.900	0.001	0.167	0.750	0.000	0.354
53	Yangqiao-Yuancun	0.667	0.750	0.008	0.083	0.004	0.665	0.688	0.105	0.353
54	Huaibei	0.500	0.500	0.083	1.000	0.042	0.243	0.625	0.687	0.352
55	Huozhou	0.833	0.750	0.165	0.500	0.032	0.270	0.750	0.055	0.352
56	Lincheng	0.833	0.625	0.053	0.400	0.002	0.432	0.688	0.154	0.350
57	Huaying-shan	1.000	0.750	0.058	0.120	0.003	0.551	0.313	1.000	0.349
58	Huhehu Depression	0.667	0.625	0.003	0.883	0.003	0.243	0.875	0.050	0.348
59	Northern Guizhou	0.833	0.750	0.062	0.267	0.211	0.378	0.563	0.417	0.346
60	Pubai	1.000	0.875	0.050	0.200	0.029	0.432	0.563	0.418	0.346

Continue

61	Hongmao	0.667	0.500	0.005	0.200	0.002	0.649	0.500	0.080	0.343
62	Maliantan	0.667	0.750	0.083	0.150	0.004	0.508	0.875	0.118	0.340
63	Zhenxiong	0.667	0.750	0.062	0.167	0.054	0.541	0.563	0.089	0.340
64	Jixi	0.833	0.625	0.033	0.133	0.042	0.486	0.875	0.077	0.337
65	Leping	0.667	0.750	0.045	0.067	0.001	0.578	0.750	0.071	0.334
66	jiyu	0.833	0.750	0.042	0.500	0.026	0.270	0.875	0.410	0.333
67	Taiyuan xishan	0.833	0.750	0.165	0.367	0.021	0.308	0.563	0.067	0.332
68	Chenghe	0.833	0.750	0.080	0.167	0.036	0.454	0.563	0.429	0.332
69	Junlian	0.667	0.750	0.062	0.167	0.018	0.578	0.250	0.089	0.330
70	Guxu	0.667	0.750	0.062	0.167	0.017	0.524	0.563	0.346	0.329
71	Huainan	0.500	0.500	0.002	1.000	0.029	0.216	0.625	0.661	0.326
72	Northwest Guizhou	0.833	0.750	0.017	0.267	0.010	0.432	0.563	0.417	0.323
73	Tongchuan	0.833	0.750	0.032	0.230	0.004	0.432	0.563	0.407	0.320
74	Qingshan-ling	0.833	0.750	0.002	0.140	0.004	0.465	0.688	0.991	0.317
75	Guiyang	0.833	0.500	0.005	0.200	0.059	0.432	0.750	0.090	0.315
76	Baiyanghe	0.667	0.625	0.003	0.464	0.003	0.335	0.875	0.000	0.313
77	Huodong	0.833	0.750	0.165	0.367	0.122	0.232	0.313	0.087	0.312
78	Zhongshan	0.833	0.750	0.002	0.100	0.002	0.470	0.563	0.851	0.306
79	Emei mountain	0.833	0.750	0.002	0.093	0.002	0.465	0.563	0.776	0.303
80	Huolin river	0.333	0.625	0.333	0.509	0.007	0.135	0.875	0.031	0.293
81	Haotiansi	0.833	0.750	0.002	0.067	0.001	0.438	0.563	0.868	0.291
82	Shuangya shan	0.667	0.625	0.192	0.400	0.004	0.135	0.875	0.073	0.281
83	Boli	0.667	0.500	0.192	0.400	0.028	0.108	0.875	0.077	0.270
84	Xingyi	0.667	0.625	0.005	0.267	0.047	0.351	0.250	0.145	0.264
85	Hegang	0.833	0.750	0.017	0.133	0.008	0.162	0.875	0.223	0.238

In addition, the method of Threshold Bound of key index screening is also applied here for further comprehensive evaluation. In this process, we consider mainly the factors such as CBM distribution area size, CBM bearing ability, ground condition and the local economic development situation. The threshold bounds are set as follows: better-than-average developed local economy, CBM-bearing area of more than 200 km^2, CBM content of more than 6 m^3/t, topography of better-than-mountain area. Based on these calculations and threshold bounds, we have obtained the screening results of 25 important CBM prospects

(See Table 3.19).

Table 3.19 Screening results of important CBM prospects in china

CBM belts	CBM prospect	CBM content (m^3/t)	CBM-bearing area (km^2)	Topography	Economy development degree
Northern margin of north china	Xuanxia	15	297.81	plain	Best developed
central hebei	Dacheng	8	3,333.55	plain	Best developed
Taihang mountain	Jiaozuo	20.1	750.45	By plain primarily, have Mountain area and hill	Better developed
Taihang mountain	Anyang-Hebi	14.4	607.53	hill	Better developed
Taihang mountain	Fengfeng	8	665.76	Low mountain and hill	Better developed
Qinsui	LuAn	9.9	3,265.27	Mountain valley	Better developed
Qinsui	Jincheng	14.1	1,348.44	Mountain	Better developed
Datong-Ningwu	Ningwu	6	849.5	Most mountain	Better developed
East fringe of Ordos	Liulin	9.7	3,338.2	loess hilly region topography gully trend	Better developed
East fringe of Ordos	Sanjiaobei	8.7	1,920.57	mountain	Better developed
East fringe of Ordos	Wubao	9	2,117.95	loess hilly region	Better developed
Weibei	Hancheng	11.8	4,309.85	mountain	Better developed
Weibei	Chenghe	8.4	1,941.22	Mountain area	Better developed
Weibei	Pubai	6	1,571.48	mountain	Better developed
Weibei	Tongchuan	6	234.34	mountain	Better developed
central Hunan-central Jiangxi	Fengcheng	17.9	722	hill	Developed
central Hunan-central Jiangxi	Yangqiao-Yuancun	12.3	221.3	Low mountain and hill	Developed
central Hunan-central Jiangxi	Lianshao	9.6	389.15	Low mountain and hill	Developed
East Sichuan	Tianfu	15.6	220.42	hill	Developed
East Sichuan	Zhongliangshan	17	255.95	hill	Developed
East Sichuan	Libixia	9.4	222.68	Low mountain, hill	Developed
East Sichuan	Luoguanshan	18.5	340.92	Low mountain, hill	Developed
East Sichuan	Qingshanling	8.6	223.94	Low mountain, hill	Developed
East Sichuan	Gufushan	17.7	417.48	Low mountain, hill	Developed
South Sichuan-Northern Guizhou	Songzao	27.1	293.94	Many mountains, hill	Developed
South Sichuan-Northern guizhou	Guxu	9.7	916.06	situated in mountain areas, complex topography	Developed

Based on the comprehensive evaluation and screening results, the CBM prospect classification is given (See Table 3.20).

Table 3.20 Classification of CBM prospects in China

Best CBM prospects： Rank 1~10	Sanjiaobei, Zhuluoxi, Hancheng, Lu-an, Daqingshan, Zhongliangshan, Jincheng, Xiangning, Liupanshui, Wubao
Better CBM prospects: Rank 11~20	Shizuishan, Tianfu, Songzao, Gufushan, Liujiang, Heshun-Zuoquan, Xinglong, Feicheng, Xuanxia, Tiefa
Appropriate CBM prospects： Rank 21~30	Jiaozuo, Liulin, Nantong, Yangquan, Hulusitai, Hongyang, Zuozishan, Ningwu, Fugu, Xuanwei
Common CBM prospects： Ranks below 30	Rujigou, Kailuan, Enhong, Luoguanshan, Pingxiang, Dacheng, Furong, Fuxin, Huayingshan middle piece, Pubai, Chenghe, Huainan, Tongchuan, etc

3.6. Summary of CBM Resources Analysis

3.6.1. Resources Conditions and Geological Features

1) CBM resource amount

China has rich CBM resources. According to the resourses evaluation, the CBM resourses with buried depth less than 2,000 m is about 35×10^{12} m^3, distributed mainly in the north and northwest of China. The geological resourses in the northern, northwestern, southern and northeastern regions accout respectively for 56.3%, 28.1%, 14.3%, 1.3% of the total national CBM resources. The CBM resourses with buried depth of less than 1000 m, of 1000 m~1500 m and of 1500 m~2000 m accout respectively for 38.8%, 28.8% and 32.4% of the total amount. About 90% of total CBM resources are distributed in the early Jurassic, Carboniferous and Permian coal seams, with the most (46.13%) in the early Jurassic coal seams and the second most (43.52%) in Carboniferous-Permian coal seams.

2) CBM basins

There are many large basins with more than 1×10^{12} cubic metres CBM resources, and they are East Ordos basin, Qinshui basin, Zhuiger basin, Yunnaeast-Guizhouwest basins, Erlian basin, Tuha basin, Talimu basin, Tianshan mountain basins and Hailaer basin. The recoverable resources in East Ordos basin and in Qinshui basin are more than 1×10^{12} m^3. The largest CBM fields in China include Ordos basin in Shanxi and Inner Mongolia, Qinshui basin in Shanxi, Tuha in Xinjiang and Liupanshui in Guizhou.

3) Geological structures

The Geological structures of coal fields are complex. Some coal basins are strongly reformed in the latter periods, forming diverse tectonic structures. The geological accumulation conditions of coal seams and CBM resources are relatively simple in large and middle large basins such as Ordos basin, but relatively complex in middle and small basins. With the support of research in CBM formation characteristics in China, the first high-rank-coal CBM field in the world and the first middle-rank-coal CBM field in China are found. We can find a large number of favorable exploration targets from these high-rank-coal fields like Qinshui ans Daning basins.

4) CBM content

The most coal seams in China are rich in CBM. According to the investigation into 105 coal fields in China, there are 43 coal fields with average CBM content of more than 10 m^3/t, which account for 41% of the total national resources. There are 29 coal fields with average CBM content of 8 m^3/t~10 m^3/t, which account for 28% of the total. There are 19 coal fields with average CBM content of 6 m^3/t~8 m^3/t, which account for 18% of the total. There are 14 coal fields with average CBM content of 4 m^3/t~6 m^3/t, which account for 13% of the total. The CBM concentration degree is relatively high, generally more than 4 m^3 CBM /per m^3 coal. The average CBM content of all the CBM fields in China is estimated as about 115×10^6 m^3/km^2.

5) Reservoir pressure

The underpressure coal reservoirs are dominant in China, only a part of them with high pressure. The lowest gradient of reservoir pressure is 2.24 KPa/m, and the highest up to 17.28 KPa/m.

6) Permeability

The permeability of the coal seams in China is relatively low, 35% with average value from 0.002×10^{-3} μm^2 to 16.17×10^{-3} μm^2. 37% of the coal seams have permeability of less than 0.10×10^{-3} μm^2. The ones with permeability from 0.1×10^{-3} μm^2 to 1.0×10^{-3} μm^2 account for 37%, and the ones with permeability of more than 1.0×10^{-3} μm^2 account for 28%. Only few coal seams have permeability of more than 10×10^{-3} μm^2.

7) Size of the CBM belts

The sizes of the CBM belts are very different. Some belts are only tens of km^2, and, others are up to ten thousands of km^2. The resources content ranges from 15×10^6 m^3/km^2 and 722×10^6 m^3/km^2.

3.6.2. CBM Resources Distribution Regionalization in China

According to the four stages regionalization such as zones, regions, belts and prospects, there are altogether 4 CBM zones, 10 CBM regions, 56 CBM belts and over 100 CBM prospects in the whole country.

1) The CBM resources on land in China are concentrated mainly in the Central Zone and the West Zone. The resource amount in the Central Zone is 20.08×10^{12} m^3, accounting for 63.81% of the total, and the resources amount in the West Zone and in the East Zone account for 25.40% and 10.7% respectively.

2) Among ten CBM regions, the largest one is the Shanxi-Shaanx-InnerMongolia region with resources amount of 17.25×10^{12} m^3, accounting for 54.83% of the total. The second largest is the Xinjiang Northern region with resource amount of 6.88×10^{12} m^3, accounting for 21.86% of the total.

3) The CBM resource quantities of the CBM belts are also very different from each others. The largest ones are the Ordos Basin North belt and the Qinshui belt. In the 56 CBM belts, there are 9 ones with CBM resources of more than 1×10^{12} m^3. These 9 belts are all located in the Shanxi-Shaanxi-InnerMongolia region and the Yunnan-Guizhou-Sichuan region in the Central Zone, and in the Xingjiang Northern region in the West Zone.

4) In the Hebei-Shandong-Henan-Anhui CBM region, there exist many CBM prospects favorable for exploration and exploitation, such as Dacheng, Jiaozuo, Anyang, Qingdignshan, Huainan and Huaibei coal fields. In the Shanxi-Shaanx-InnerMongolia region, there are also many CBM prospects favorable for exploration and exploitation, such as Yangquan, Shouyang, youan, Linxing, Tunliu, Jincheng, Liulin, Sanjiao Hancheng and so on. These regions and prospects are currently the most active areas of CBM exploration and exploitation, and they are expected as good development prospect regions.

3.6.3. The Favorable Cbm Development Areas

1) Three indices, namely the resources density, CBM resources amount and CBM content, are selected as the basis for ranking of CBM belts. First the index dada were processed, and then the comprehensive evaluation and ranking analysis were done by means of weighted average calculation method. According to these ranking analysis, the first 20 CBM belts are Qinshui, North Ordos Basin, Huoxi, Liupanshui, Tuha, Zuo-He, Ordos Basin East Edge, Henan East, Taihangshan East Foot, Weibei, Henan West, Yili, Hebei Central Plain, Daning, Hunan Sourth, Anhui Sourth, Beijing-Tangshan, South-Sichuan-North Guizhou, Middle Hunan.

2) For ranking of CBM prospects, the coal rank, buried depth, permeability, thickness, CBM-bearing area, CBM content, ground conditions and market demand are selected as the specific indices. The comprehensive evaluation and ranking results about the 85 prospects were given. Through further analysis, suggestions are also given about the classification of the target prospects into 4 groups such as the best CBM prospects, the better CBM prospects, the appropriate CBM prospects and the common CBM prospects.

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Chapter 4 CBM Exploration and Production Technology

In China, CBM geological studies began in the 1980s, and its almost 20 years of exploration can be roughly divided into 4 phases: technology introduction phase, the evaluation phase, and exploration and research phase, development and testing stage. At present, among the restrains to commercial development of the CBM, technology to find CBM enrichment hypertonic zone and the technology to enhance the CBM recovery is most serious. This chapter will introduce exploration and development technology of coal seam from other countries. It will focus on Chinese exploration and development of CBM in the technical aspects of the research progress at the same time, mainly including CBM geophysical techniques, drilling technology, mining technology, production technology. At the same time, the output of existing different well patterns in target areas is simulated on the basis of technology available.

4.1. Overview and Prediction of Key Geophysical Exploration Technology

CBM geophysical probing technology mainly includes logging technology and seismic exploration technology. The purpose of CBM logging is to solve the stratigraphic classification, lithology discrimination, confirmation of the depth and thickness of leat, to calculate the fixed carbon, ash and moisture of coal seams, to estimate volatile constituent and gas content and to make the analysis of the fluid, aquosity and permeability. Seismic technology is mainly to detect the coal accumulation, structural feature, development of fault, and to identify the thickness of the coal bed in qualitative and semi-quantitative way [1].

4.1.1. CBM Geophysical Techniques both At Home and Abroad

4.1.1.1. CBM Logging Technology

1) CBM logging methods

There are many types of CBM logging methods, each of which is directed at the seam with a logging response. The logging depth is generally less than 2,000 m since coal bed is often in a low desorption zone under 2,000 m, which is not conducive to the exploration of CBM.

The United States used density logging (high definition density logging, litho density logging), caliper logging, dual lateral logging, microelectric logging, resistivity logging, SP logging, neutron logging, acoustic wavetrain logging, FMS and so on in the exploration and development of black trojan coal-bed methane field.

China has also done a lot of work for the CBM logging technology study: developed a series of CBM logging and evaluation software; used neural network method to calculate ash content, then calculate gas content, which can qualitatively determine seam permeability; re-established seam gas content interpretation model in Jincheng, Wubao and Daning-Jixian areas by comparing logging data with core analysis data, the absolute error of coal seam gas content is 1.36 m^3/t~2.24 m^3/t, which improve the accuracy of the log interpretation.

The classification of Chinese CBM logging methods applied [2] (See Table 4.1), basically shows the currently used CBM logging methods.

In China, there are 8 logging methods which can not only reduce costs but also solve practical problems, such as compensated neutron log, compensated density log, compensated sonic log, deep investigation laterolog, shallow laterology, natural gamma ray log, SP log and caliper logging. However, in order to solve some special geological problems, usually more items need to be tested, such as NMR, CAST, micro-resistivity scanning log, multi-array acoustic logging, natural gamma ray spectrology and dipmeter survey. However, it is worth noting that: some agencies are doing effective research in logging methods, logging data acquisition interpretation, evaluating rock coal, and calculating gas content. The best logging methods are supposed to be density logging, acoustic logging, gamma ray logging, resistivity logging (LLD, LLS) and caliper logging (CAL1, CAL2). Other subservience logging methods include natural SP logging and temperature logging [3].

2) CBM reservoir logging evaluation technology

The features of CBM reservoir log evaluation technique are high-resolution, effective differentiation, rapid, intuitive and low cost. Much work has been done in CBM reservoir log evaluation technique and in theoretical studies in the aspect at home and abroad. The United States and other western countries have been working on developing corresponding physical model and empirical formula for reservoir parameters evaluation. Some study has been done also in China according to the geological condition and reservoir characterization in China: and such activities include: to do some research on the data acquisition and interpretation of the relevant methods; to carry out research in calculation method of porosity and gas content by using neural networks method, fuzzy pattern recognition, multivariate statistical theory, grey system theory and fractured reservoir evaluation theory [4].

From the analysis of existing research, CBM reservoir log evaluation techniques can be roughly divided into qualitative recognition method based on gas reservoir evaluation, evaluation method based on the volume model, evaluation method based on probability statistic model and evaluation method based on the neural network model [5] as shown in Table 4.2.

Systematic and practical evaluation of CBM logging technology system has not yet been developed although certain progress has been made in CBM research work both at home and abroad. Therefore, a comprehensive and systematic study of reservoir evaluation logging technology theories is necessary.

Table 4.1 CBM Logging model

<table>
<tr><td rowspan="18">CBM Logging method</td><td rowspan="9">Basic logging method</td><td rowspan="3">lithologic log</td><td>S.P.log</td></tr>
<tr><td>Combination gamma ray neutron laterolog</td></tr>
<tr><td>caliper log</td></tr>
<tr><td rowspan="2">saturation log</td><td>Dual laterolog-microspherically foused log</td></tr>
<tr><td>Dual induction laterolog</td></tr>
<tr><td rowspan="4">porosity log</td><td>compensated densilog</td></tr>
<tr><td>neutron porosity log</td></tr>
<tr><td>acoustic travel time log</td></tr>
<tr><td>microlog</td></tr>
<tr><td rowspan="9">Assistant logging</td><td>diplog</td><td rowspan="9"></td></tr>
<tr><td>acoustic wavetrain logging</td></tr>
<tr><td>SGR</td></tr>
<tr><td>acoustic variable density log</td></tr>
<tr><td>density log</td></tr>
<tr><td>neutron log</td></tr>
<tr><td>acoustic log</td></tr>
<tr><td>neutron spectrum</td></tr>
<tr><td>drift log</td></tr>
</table>

Source: Wang Dunze, 2003.

4.1.1.2. CBM Seismic Technology

Seismic exploration is the use of artificial methods of elastic wave excitation in positioning minerals (including oil, ores, water, geothermal resources, etc.) to get engineering geological information. Seismic data combined with the other geophysical data, drilling information, geological data and the corresponding physical and geological concepts tend to include structure information [6].

CBM seismic exploration can be divided into seismic data acquisition, seismic data processing and interpretation of seismic data. Each stage has its own specific requirements [7] (as shown in Table 4.3).

In recent years, CBM seismic technology has been experiencing much development. PC computers have been used in large-scale, and visualization, virtual reality, network technology got rapid development. High-resolution seismic, 3D seismic, and 3D seismic exploration AVO technology, seismic attributes, and 4D seismic, CT crosswell seismic testing technology, multi-component seismic method (3D3C method) are also well developed, which has played an important role in the development of CBM.

Table 4.2 CBM Evaluation Techniques

Technology Category	The main principle	Review
The qualitative identification method based on the conventional gas reservoir evaluation	Similar to the conventional gas reservoir log response mode (such as, high resistance, acoustic increased, low-density and high-porosity, etc.), based on the known regular change pattern from single or a few logging curves, through summary of such regular pattern, propose qualitative recognition norms.	Only for reservoir qualitative recognition; And when some logging data are interfered, the results may be wrong。
Evaluation method based on the volume model	The idea is similar to the traditional volume model, but it also properly takes some characteristics of the CBM reservoir into consideration. Based on Logging volume model, it builds the linear or nonlinear relationship between log response (acoustic, density and resistivity) and reservoir parameters (porosity and gas saturation, etc.), and then obtain reservoir parameters.	Application premise assumes that the structure of coal reservoir has heterogeneity and isotropy, which is obviously inconsistent with the actual reservoir structure, so there some errors may occur with this method.
Evaluation method based on probability statistic model	The method takes the reservoir parameters, results of qualitative identification information and log response as random variables, does statistical analysis of these variables from prospect of probability statistic theory and gets the reservoir evaluation formula from the statistic analysis of known data and information and then concludes reservoir evaluation.	Application premise is to assume that the reservoir parameters and logging information subject to a probability statistical distribution. There is a (linear or nonlinear) relationship between reservoir evaluation and log response. If the condition is not there, the results are difficult to meet the accuracy requirements.
Evaluation method based on the neural network model	Based on the fact that modern nonlinear reservoir evaluation method can be used for the whole process of evaluation of CBM reservoirs, which include the reservoir qualitative identification, quantitative calculation of reservoir parameters, the comprehensive evaluation of reservoir, the neural network method does not use the concrete mathematical model, and it can express complex relationship between reservoir evaluation results and logging response information, thus achieve reservoir evaluation. Currently, almost 100 neural network models have been raised.	Generally, a BP neural networks and self-organizing neural network (no teachers' instruction network) are good and mature method. Although BP neural network is of comparatively good effects, there still exist some disadvantages like low iteration speed and local minimization spot.

Source: Hou Junsheng, 1998.

4.1.2. Applicability Analysis of Key Geophysical Exploration Technology

4.1.2.1. CBM Logging Technology Application Analysis

In the process of CBM development, CBM reservoir parameters that can be identified by current logging methods include: coal formation lithology profile, CBM reservoir gas content, coal volume and porosity, coal permeability evaluation, coal reservoir cracks, coal thickness, coal mechanical characteristics parameters and so on.

The main lithology of Chinese coal formation is sandstone, mudstone and coal. Some districts have thick carbonate formations. Drilling coal-bed methane wells will identify the profiles of the rocks by observing the core, cuttings and gas survey, and then precede lithology reparations by electric information.

Table 4.3 CBM seismic exploration phase

<table>
<tr><td rowspan="8">Seismic data acquisition</td><td colspan="2">Effective wave and disturbing wave judgement</td></tr>
<tr><td rowspan="2">Layout</td><td>2D seismic</td></tr>
<tr><td>3D seismic</td></tr>
<tr><td rowspan="5">The main parameters observing system</td><td>Vertical resolution</td></tr>
<tr><td>Coverage Analysis</td></tr>
<tr><td>Sampling rate analysis</td></tr>
<tr><td>The largest offset analysis</td></tr>
<tr><td>Rectifier and association analysis</td></tr>
<tr><td rowspan="5">Seismic data processing</td><td colspan="2">Precise calculation of static correction</td></tr>
<tr><td colspan="2">Excluding poor cannon, poor road and abnormal amplitude numeric value</td></tr>
<tr><td colspan="2">Choose a suitable deconvolution parameter</td></tr>
<tr><td colspan="2">Doing remaining static correction by exact velocity analysis and multiple iterate</td></tr>
<tr><td colspan="2">Fine post stack processing and deviation migration</td></tr>
<tr><td rowspan="5">Seismic data interpretation</td><td colspan="2">Interpretation methods</td></tr>
<tr><td colspan="2">Horizon feature and composite wave feature</td></tr>
<tr><td colspan="2">Speed studies and mapping methods</td></tr>
<tr><td rowspan="2">Structural interpretation of seismic data</td><td>Conventional structural interpretation</td></tr>
<tr><td>Special structures interpretation</td></tr>
</table>

The methods of commonly used for measuring gas content include: concept analysis by using the volume model and S-P interval qualitatively to determine coal-bed methane content, and use density logging and Langmuir equation to quantitatively determine coal-bed methane content.

Porosity and pore volume of coal seams are important parameters. Nuclear magnetic resonance logging is the most effective method to determine actual porosity of coal seams, but we should understand the impact of its mistakes.

A series of logging for coal seams permeability evaluation include micro-resistivity logging, micro-electric logging, SP logging (self-potential logging), formation micro-resistivity scan logging, acoustic logging, and the first two are the most commonly used. To evaluate coal seam permeability quantitatively, first we need to calculate seam cracks with dual lateral log (LLD), and then evaluate reservoir permeability with reference to the relevant equation we get form graphics technology.

Microlaterolog, dual lateral logging, image logging are main methods for studying cracks on the coal seams. The values of microlaterolog are affected by the electric conductivity of drill fluid. If coal bed has high resistivity and vertical cracks, there is positive separation in dual lateral logging, and the difference depends on drilling fluid resistivity, formation water resistivit, and fracture developmental situation. The resolution of Circumferential Borehole Imaging Log is higher, and can identify aeolotropism which is created by cleap kerf.

Using log data to divide the interface depth between coal bed and adjacent rock accurately is also called thickness division. The cutoff value of density log can determine the border of coal bed, and then determine the depth and thickness of coal bed. Gamma ray log, volume density log and resistivity log can determine the thickness of coal bed effectively.

Evaluating mining machine characteristic parameters, China started to use Multipole Array Acoustic Log in1997. Multipole Array Acoustic Log can precisely determine the parameter of longitudinal wave and shear wave. Using density log, longitudinal wave time difference, transverse wave time difference can identify Young's modulus, bulk modulus, shear modulus, maximum and minimal horizontal stress, overlying formation stress, drilling fluid stress, circumferential stress, radial stress, breakdown pressure, caving pressure, Poisson ratio, Schlumberger ratio, fracture index and so on. These parameters can be used to complete mechanical characteristic log interpretation which is between coal bed and adjacent rock, crustal stress log interpretation, packer property log interpretation in adjacent rock, hole stability log interpretation, formation strength log interpretation, fracturing design, created fracture height in hydraulic cracking, in order to provide reference data for coal-bed methane production.

4.1.2.2. CBM Seismic Survey Technology Application Analysis

Three-dimensioned seismic survey AVO technology is a technology directly for coal-bed methane exploration. The main principle is to use the alternation of seismic wave amplitude with the alternation of the offset (incident angle), and to predict gas enrichment site. According to reports, the United States is more successful because of its more leading-edge technology. Some Chinese scholars did some useful work in forecasting coal-bed methane concentration characteristics by using AVO technology. They studied AVO anomalous characteristics which is affected by coal thickness, measured the wave velocity characteristics under confinement pressure in laboratory; and did systematic research focusing on gas enrichment by using AVO technology in mines.

Multi-component seismic technology as the extension of longitudinal wave processing is effectively applied in converted wave processing, but is quite immature. During the development of multi-component seismic technology, anisotropic medium conversion imaging technology is the key point in recently years, which is the key to the solution of complex geology, tectonic imaging.

The principle of cross-borehole acoustic tomography (cross-borehole CT method) is to send and receive signals by changing the positions between source and receiver, so that a great number of seismic ray run through cross hole section. This method can describe coal condition (thickness, form, depth and so on), and can study the faulted structure, the plane and vertical distribution of fracture formed after coal fracture.

4.1.3. Technical Demand and Target for Development of Key Technology

4.1.3.1. The Problems and Prospects of CBM Logging

Coal seam characteristics determine its strong heterogeneity and anisotropy, resulting in greater difficulties for log data interpretation .The key problems include:

1) It is still difficult to directly calculate methane content and to evaluate the coal bed with logging methods. Although some scholars developed coal-bed methane content of the estimated model, there are still restrictions to location, and the content can not be directly calculated.

2) Calculating the porosity and permeability of coal bed is very difficult. Using previously developed estimation formula may lead to mistakes.

3) There were no more universally applicable approach to quantitative calculation of coal seam parameters and evaluation of fracture permeability of the coal seams, a resistance to logging technology popularization and application.

4) As CBM logging technology was introduced from abroad initially and borrowed from conventional reservoirs logging technology. It needs further tests to determine the applicability of various logging methods and logging technology to China coal bed geological features.

To solve aforementioned problems, three measures should be taken: to strengthen the basic theoretical research in CBM logging; to develop and introduce new logging methods; to study reservoir evaluation processing and interpretation software system.

4.1.3.2. CBM Seismic Exploration Technology and Prospect

With intensified development of the CBM exploration, geophysical exploration is now transforming from a mere exploration tool to reservoir description and monitoring tools. A great deal of surface data (mainly seismic data) and formation data (VSP, logging, drilling, testing, production, etc.) are integrated, so that we can get more formation data from the surface data. As for seismic exploration for CBM, three aspects need discussing: the inversion of seismic data from post stack to pre-stack; correct application of seismic property technique to 3-D seismic interpretation, to reservoir parameter description, and to Coal Gas Disaster Prevention which has important practical significance; more investigations from CBM point of view into 3-D3-C seismic data processing technology as improvement and extension of longitudinal wave processing technology to promote the development of 3-D3-C seismic data processing technology [2].

4.2. Outlook and Prediction of Key Drilling Technology

4.2.1. Present Situation, Development Trend Analysis Abroad

The CBM development abroad has made large technical progress in recent years, especially in the United States, Canada and Australia. But because of different coal bed geological conditions and development environment in different countries, the exploration and development technology must be different.

The United States is the most successful country in CBM industry development, and the drilling technology used there is the most mature and advanced. The United States, where the coal bed geological condition is relatively good, generally using air, gas spray, aerated mud and formation water as fluid to drill in under-balanced way and then completed wells barefootedly. In the United States, there is nearly 90% of wells using under-balance drilling technology which plays a critical role in CBM development. The most outstanding technology of the United States is multi-branched well technology of CDX Co. as shown in Figure 4.1, which is more suitable for well-developed coal seams and more effective to low permeability thin seams. By Aug. 2006, more than 170 wells of that kind were drilled by CDX Company [9,10]. Besides, bare hole cave completion technology also plays an important role in the United States' CBM development, which is mainly suitable for low permeability but un-effective for low permeability layers.

Canada has made great progress in multi-lateral well drilling technology, developed from the research based on the characteristics of mainly low rank coal; reduced the formation damage and cut down the drilling cost by using coiled tubing drilling technology,.

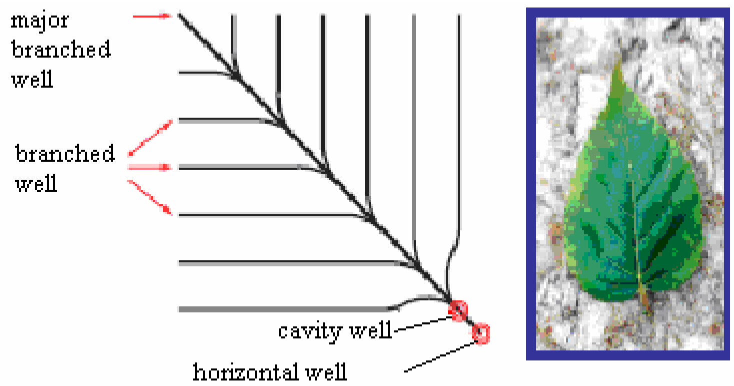

Figure 4.1 Sketch figure of the CDX company' multi-branch horizontal well
Source: Maurice Smith, 2003.

4.2.2. Present Situation and Development Trend of Key Drilling Technologies in China

The surface drilling technology has a late start in China, and most of such techniques are developed on the basis of local coal conditions, by referring to the technology abroad.

At present, the well styles of CBM in China are mainly vertical well (including cluster wells) and multi-branched wells and vertical well drilling technology is the most mature with lower cost and easy operation, and therefore this technology is widely used in China. Moreover, cluster wells, which need low orographic conditions and are suitable for hilly districts, has been used for the first time in Qinnan Basin CBM development; multi-branched well drilling technology has just been developed, which has some technical risk at present. Multi-branch wells have advantages of large drainage area, high output, with recovery as high as 85%. But the new domestic multi-branch horizontal well technology has certain technological risks, with success ratio of only about 50%.

But as for drilling methods, there are mainly under-balanced drilling and nearly balanced drilling like free water drilling, low solid or clay free drilling and air drilling. The function is to reduce formation damage and improve single well production.

In regards to coring technology, wire line coring technology is often used in China and it has advantages as follows: coring outer barrel has two separate structures and the inner barrel assemblage can be lifted to well head from boring tool without tripping out after coring, and thus, the coring speed is fast and the yield is high. This technology not only shortens the tripping out time but also get coring uninterruptedly without tripping out.

As for well completion, because most wells are vertical, the mature casing perforating completion technology is mainly used, for its easy operation and full supporting technology, in order to satisfy the post operations. Conventional open hole completion technique is use for trial in China, but hasn't been promoted. Cave well completion technology is tested in Shouyang, Sanjiao, Liulin in Shanxi Province and Fengcheng in Jiangxi Province, and the results are far from ideal. Moreover, mini cave well completion technology is carried on in Shenbei Coal Mine and shows promising effect.

Cementing technology is also critical for CBM development. In order to reduce the formation damage by slurry cement and to ensure the stress of cement sheath, low density cementing and mud return height controlling technology are mainly used, and acoustic amplitude log and variable density log are adopted to check cementing quality.

4.2.3. Applicability Analysis of Key Technologies in Drilling, Coring, Completing and Cementing Technology in China

4.2.3.1. Applicability Analysis of Key Drilling Technology

Coal bed is easy to be contaminated during the process of drilling. We can adopt these technologies to decrease or prevent the damage: firstly, lower the density of drilling mud or use air foam drilling to perform near-balanced drilling or under-balanced drilling; secondly, control the content of solid material and macromolecular compound to prevent coal-bed jam by solid grain; thirdly, choose proper drilling mud suitable for the coal-bed fluid and control the water loss of drilling fluid strictly to prevent hydrate expansion, water blocking damage and insoluble precipitate caused by sensitive reactions, reduce coal soak time by accelerating drilling in coal seams [11]. In addition, because of low production rate, other well types should be considered. Multi-branched wells, which have already been used and popularized in China, can solve this problem.

1) Free water drilling.

Coal bed is generally of low pressure and is damaged by high pressure mud. Therefore, it is not appreciated to use high density mud to drill in coal seam. It is proposed to use water suitable for coal bed to drill, which decreases formation damage and cut down drilling cost.

Free water drilling has low cutting lifting ability and weak well bore stability. It is necessary to control mud density well to perform near-balanced drilling, and to enhance mud recycle to ensure good cutting lifting ability, stabilize and protect well bore. Free water drilling usually uses conventional rig such as ZJ-15 Rig and TSJ-2000 Rig, and solid phase controlling apparatus are often needed. In Qinnan Basin, more than 600 CBM wells were drilled successfully by free water technology.

2) Low solid or clay free fluid drilling technique.

Low solid fluid drilling technology and clay free fluid drilling technology are both important ways to decrease drilling damage approved by years' CBM tests [12]. This fluid is suitable for coal bed where abnormal layer pressure or unstable wall exists. It contains inorganic salt, polymer and temporary blocking agent and is widely used in the CBM wells. Taking testing well Jinshi-1 as example, in conventional sand profile, bentonitic drilling mud is used in the initial flow period, low-density polymer drilling mud with little solid material is used during the second period, and low-density and clay free drilling fluid with KCl is used in third period from entering coal seam to well completion. In the whole process, compatibility between fluid and coal seam is monitored, density of fluid is controlled strictly, and drilling speed was accelerated in order to decrease the formation damage.

3) Air drilling technique.

Air drilling mainly uses air foam as recirculated medium and downhole percussion drilling technique. In addition to conventional drilling outfits, it requires flowhead control swivels, air compressors, booster compressors, foam pumps, inside blowout preventers and so on.

Air drilling is under-balanced, with high drilling speed and low cost. Little water loss and low drilling pressure could reduce invasion to coal seams by filtrate outside to protect coal bed. Foam structures could shut off micro-fractures and then protect them. High drilling speed and short drilling term could improve drilling efficiency and cut total cost down.

Air foam can't carry hole stabilizing agent, and therefore, air drilling cannot penetrate unstable layers directly. When the drilling bit touches saturated water, particles may cause blocking. There is fluid in the annular wetting shale sensitive to water and the wet shale could stick together at ectooecium of drilling pipes and then forms mud cake there. It can't be lifted by air foam from the annular. If it fills the annular up and then prevents air from flowing, it would cause hole-sloughing and bit freezing. And when big air slugs move up along the wellbore, hole instability would be caused. Therefore, insuring hole stability while drilling is very important. In addition, because there is no fluid in borehole during air drilling, it will produce heat due to fracturing between bit and formation. Excessive heat could make cone bits seal failure and tooth of diamond bits burnt out. So, to cool bits well is also very important.

Air drilling technology is suitable for the shallow formations with low pressure, old geologic age, solid and fracture developed.

4) Technology for multi branch well

a. Advantages and adaptive conditions of multi-branched well

Multi branch well is composed of a primary well bore and two or more branch well bores. Multi branch wells from the side track of the existing well can be divided into 6 types (Figure 4.2), such as viaduct-like multi branch well, claw-like 3-branch well, fork-like multi branch well, pterate multi-branched well, pinnate multi-branched well and herringbone multi branch well. It can also be divided into plat and vacuity multi branch wells from the distribution prospect.

Generally CBM multi branch well is more applicable to coal bed with high SATG, stable mechanical features, continuous lateral distribution, continuous and stable coal bed in the landscape orientation, no shatter belt, no much sand shale interlayer fault and with very few faults and pinch-out of coal seam, and it is especially effective in low permeable sublayers and high gas areas.

Compared to conventional vertical well, it has several advantages: enlarged effective drainage area; improved flow conductivity; decreased harm to coal bed; higher single well production, and therefore it has wide application prospect.

b. Situation of multi-branched well application in China

The research in multi-branched well technology in China was developed late. But recently many companies, such as China United Coalbed Methane Corp., CNPC, North China and CDX, Changqing Oil Field, Liaohe Oil Field, FEEC (Far East Energy Corporation), have started exploiting CBM by pinnate multi branch well. In recent years, many of those wells have been drilled.

The first domestic CBM multi branch well named Well DNP02 in Shanxi Qinshui Basin was drilled in November 2004. The rate of drilling coal formation of this well is up to 90% and the largest hole deviation angle reaches 101.47°, and the technology used are under-balanced drilling technology and LWD technology and double breakthroughs are made both in desired technology and productivity (See Figure 4.3, Table 4.4). The success of Well DNP02 set a milestone for CBM development history in China.

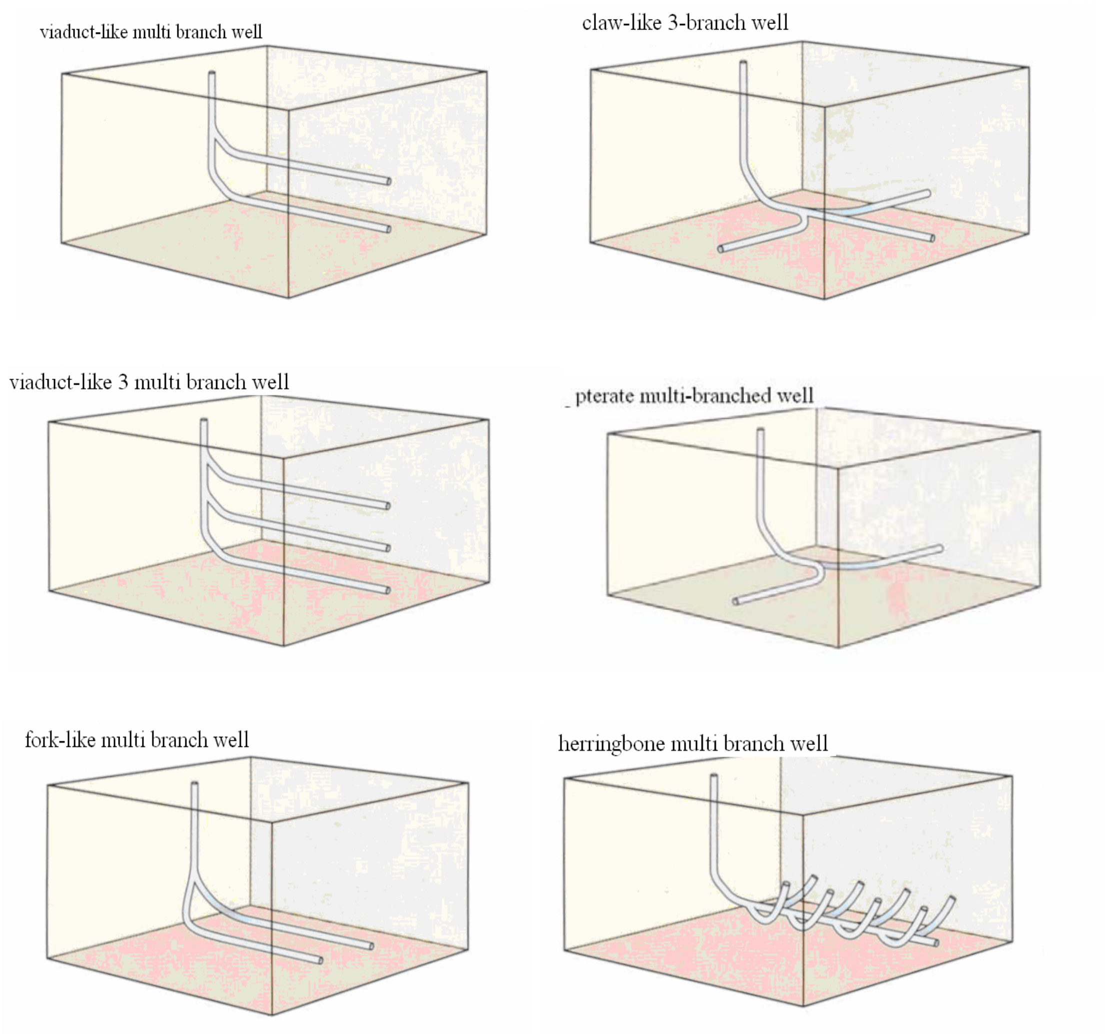

Figure 4.2 Types of Multi Branch Well

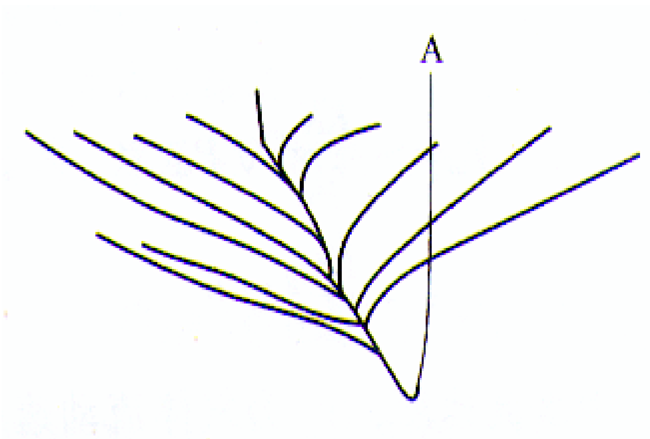

Figure 4.3 Real well track of DNP02 (Zhang Yapu, 2005.)

In Oct. 2005, Well Wu M1-1 was drilled by CNPC in Shanxi Qinshui Basin (See Figure 4.4). The structure of Well Wu M1-1 was double barreled. Some international advanced technologies, such as cave created in coal formation, end-to-end joint of two wells, geosteering while drilling, horizontal multi-branched, aerating under-balanced drilling technology were completely applied to Well WuM1-1. It completed the exploration drilling task as designed. The total drilling footage of well group is 7,993 m and it has achieved the designed purpose.

In Feb. 2006, Well DS-01 was drilled by China CBM Company which has accumulated footage of 6526m and footage in coal seam of 5,430 m [13].

On Jan. 27 2007, a horizontal well group of 6 wells or 3-set wells was finished in Panzhuang CBM area of Jincheng (See Figure 4.5). It is the first time to apply synthesizing technical characteristics of cluster well and multi-branched well in form of well group, and to undertaking drilling in coal seam in two horizontal directions from surface through a main horizontal hole in China. It adopts hole pattern of single bottom multi hole pattern, of which footage in single seam is up to 3,000 m~5,000 m and rate of drilling in coal formation reaches over 95%. At present, all of 6 wells have been put on stream, and achieved average single well production of over 50,000 m^3, and some even exceed 80,000 m^3 and keep on rising. The success of horizontal well group in Panzhuang tells that this technology is gradually becoming mature and suitable for CBM resource in the target blocks. It is of great significance to CBM development in China [14].

Table 4.4 Main parameters of DNP02 well

Beginning date	07/10/2004
Production date	28/11/2004
Horizontal wellbore diameter (mm)	150
Vertical depth (m)	195
Horizontal displacement of main wellbore	1256
Number of branch	12
Horizontal footage(m)	7687
Footage (m)	8018

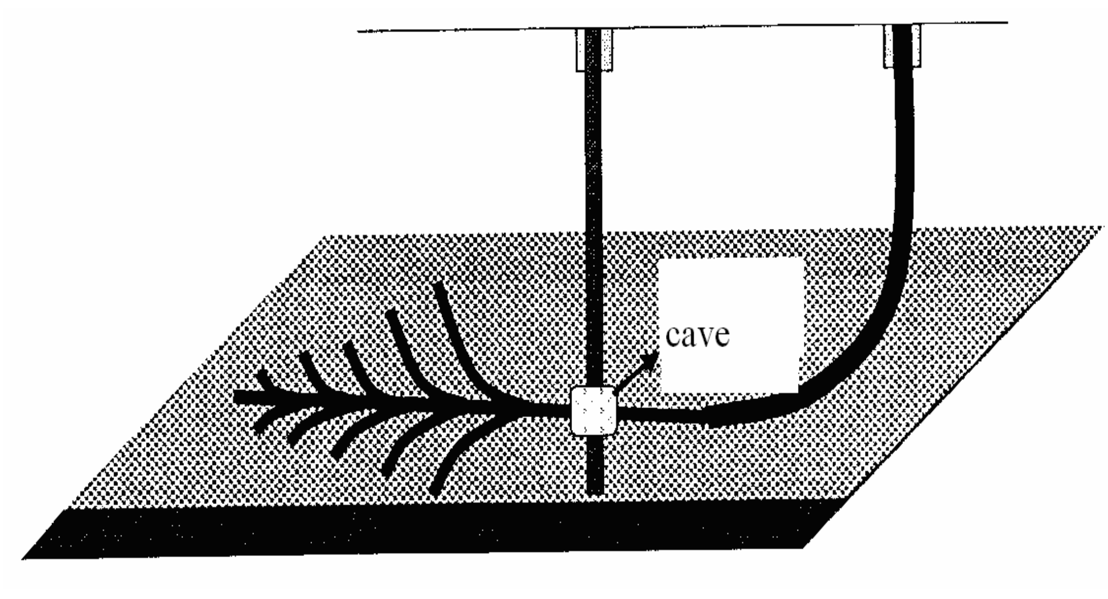

Figure 4.4 Well structure of Wu M 1-1

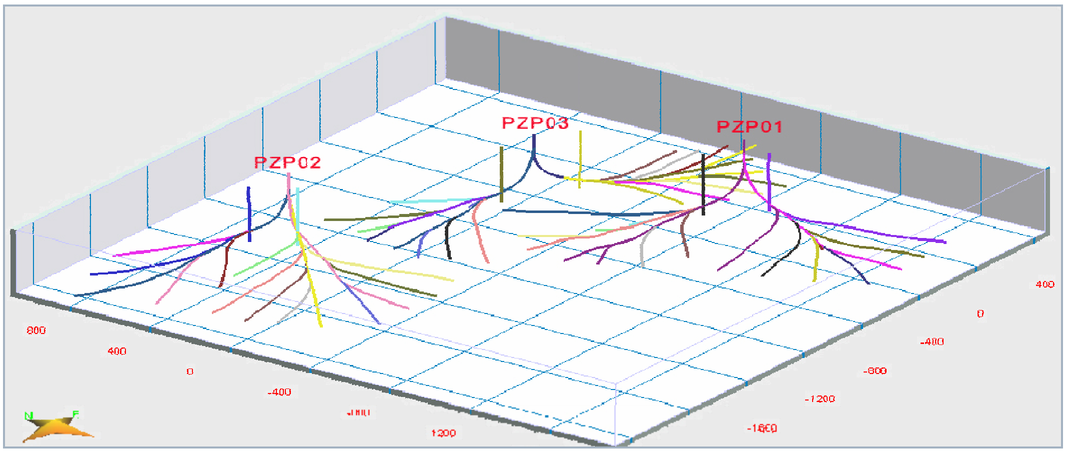

Figure 4.5 Wellbore track three dimention figure of the multi-branch horizontal well group
Source: Yang Luwu, Second CBM Symposium of China, 2007.

c. The critical technology of multi-branched well and the solutions.

According to the experiences of multi-branched well development, technology of communication between engineering well and horizontal well, technology of well path controlling and hole stabilizing technology are pivotal for multi-branched wells [15~22].

i. Technology for communicating engineering well with horizontal well

Generally, multi-branched well is drilled in the formation of high anisotropism, great thickness and relative stability. First a vertical well is drilled, and then cave to make horizontal wells get through. However, because of the vertical well path drifting, the limit of open hole cave diameter and precision impact of monitoring when drilling in the host bore hole angle making, it is quite difficult to connect two wells. At present, the main solutions is: first, to do multimeter and gyroscopic survey to the vertical well to specify the curve of open hole cave and well depth position; then to use cement plug to shut off the hole below the bare hole caver, and to connect two afterward. It could avoid the bit entry into the bore hole because of the gravity when getting through the bare hole cave (See Figure 4.6).

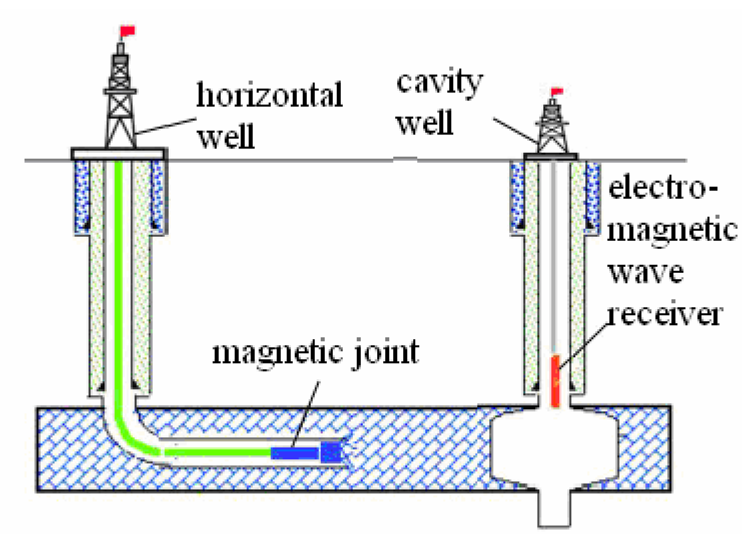

Figure 4.6 Sketch figure of two wells connection (Qiaolei, etc, 2007.)

ii. Technology of well path controlling

Path controlling of CBM multi-branched horizontal well is difficult. In the drilling process, the phenomena such as small ledge, bottom hole slough, difficult hoisting and key seating sticking are common problems. Generally, the angle building section of main horizontal hole adopts directional tool assembly of "direction guiding motor + survey steering tool". In the main horizontal well, LWD is used to monitor the natural gamma value and the electronic resistivity value to tell if the bit in coal seam is running well. Gliding continuous drilling method and real-time control are applied to enhance the precision of well path controlling. To keep bore hole path smooth and avoid great curvature undulation of well track follows. Avoid change in the structure, scale and drilling parameters of bottom hole drilling assembly and control drilling rate well. And it is supposed to keep the path of the main horizontal well in the top of coal seam to insure well safety and easy drilling of lateral wells. As for branched wells, at present, there are 3 kinds of sidetrack drilling technology often used in oil drilling: the first one is side tracking with cement plugs; the second is side tracking with retrievable bare hole excluder/ whipstock; and the third is pending sidetrack drilling. According to international experiences, when drilling the branch hole, retrievable bare hole excluder/ whipstock is generally used to drill sidetrack, which is of high success rate but needs many construction programs and some special tools. Recently, there is no retrievable bare hole excluder/ whipstock which must be imported or developed through domestic endeavour. Expending sidetracking is a control technology used in recent years, which has quite simple process and easy to apply. At present, the multi-branch horizontal wells in Qinshui Basin are mainly using pending sidetrack drilling to drill branch wells. Directional well engineers may judge the sidetrack drilling whether succeeds promptly according to differential pressure of motor, inclinometer data, change of drilling parameters and so on. After sidetracking, the well path controlling is similar to that of main horizontal well. Using this technology, Orion Energy International Company has drilled some multi branch wells in Qinshui Basin, and the footage rate drilling in coal formation of these wells is up to over 90%.

iii. Hole stabilizing technology

Hole stabilizing technology is critical for multi-branched wells. It is mainly conducted by optimizing well bore structural design, controlling drilling fluid density reasonably and adopting other bore holes stabilizing technology or measures. 1. To optimize well bore structural design: technical casing cannot run to coal seam to prevent coal-bed fracture when cementing and causes borehole wall sloughing during the sequent drilling process; technical casing of horizontal well cannot reach angle building section and is proposed to be run above of the kick off point, in order to perform sequent barefoot sidetracking drilling. It is proposed to keep horizontal wells and branch wells in the top of coal seam to insure drilling safety. 2. to control drilling fluid density to a reasonable degree: the density of drilling fluid has great effects on borehole stability. If the drilling fluid density is low, because of low tensile strength and elasticity coefficient of coal, it may cause the tectonic stress releasing, and then brings coal breaking up and sloughing along cleats and cracks. But if it is excessively high, the drilling fluid may enter the coal bed under the differential pressure function, which can not only destroy coal bed fracture structure, but also cause damage to the coal bed, and directly affect the CBM desorption, diffusion, migration and production in the later period. The drilling fluid also should have good lubricating ability, rejection capability, cutting carrying capacity and anti-collapse performance. Control the water loss and the chemical property of filtrate strictly, enhance the filtrate viscosity suitably, reduce or weaken the capillary effect, and decrease the permeability of filter cake. 3. To adopt other borehole stabilizing technology or measures: the formation below the kick off point is proposed to use dynadrill to drill, irrotational drill stems are relatively stable which is helpful for keeping bore holes stability; to use simple structure drill assembly to reduce collision when making a trip; to reduce the drilling time of horizontal well section to decrease the soak time of coal in drill fluid.

Although there are successful cases of CBM multi-branched horizontal wells in China, there are also many technical problems to solve and to use the technology is risky. Because multi-branched horizontal well is suitable for low permeability formation, vertical wells cannot take its position for its ability to get high single well production. It will certainly make the unprecedented progress and play an important role in the CBM development and exploration in China.

4.2.3.2. Applicability Analysis of Key Coring Technology Used in China

The physical properties of coal bed are poorer than those of the conventional gas reservoirs. The CBM well coring needs not only to stabilize the structure, rank, permeability, porosity, cleat attribute and other parameters of coal, but also to measure gas content, desorption pressure, adsorption isotherm curve on site. It also requires the coal core maintaining the original condition as much as possible. All of the factors above make the CBM coring technology different from conventional coring.

Generally speaking, there are four kinds of coring technology in CBM development: conventional coring, sidewall coring, wire line coring and pressure coring respectively. Conventional coring needs pulling strings out and it takes a longer time, and further the gas escape takes a longer time and gas content measured is inaccurate. It is difficult to get complete coal sample by wire line coring and the sample is small in size. The excessively small coal sample may lead to incorrect measurement of gas content, lower than actual content. Gas content measured by pressure coring is the most accurate, but the costs are high. Wire line coring is often used in China, and the advantages are high coring speed and high core recovery. In addition, this technology could core uninterruptedly without tripping out and the gas content measurement is quite accurate [23].

The wire line coring tool is generally composed of coring bit, outer barrel assembly, inner barrel assembly, semi-closed core tube, suspension unit, shell fragment locating unit, core cutting and chucking unit, single acting unit, alarm device, differential system, internal/external centering device, fisher, wire line lifting system [24] (See Figure 4.7).

The general work principle of wire line coring tool is that: put in tube assembly before coring and start drilling, and then set suspension hoop to socket ring of outer tube. When inner barrel is in place, start to drill and core. When coring is finished, stop the pump and lift the core to surface without tripping out but bring up the inner tube to the surface by the fisher with wire line through the drill pipes. Ahead of this process, the blind gripper is preventing fragment seals the bottom of inner tube off to prevent the coal core and pieces dropping. After unloading the connection screw thread in the middle of inner tube, extract the core sample accommodation tube, and finally the coal core exposes. After taking the core out, fix inner tube assembly, and put it to the bottom hole again. Repeat the process above to continue drilling and coring. It is supposed to keep “four lows” in the coring process, namely low drill pressure, low revolution speed, low displacement and low pump pressure.

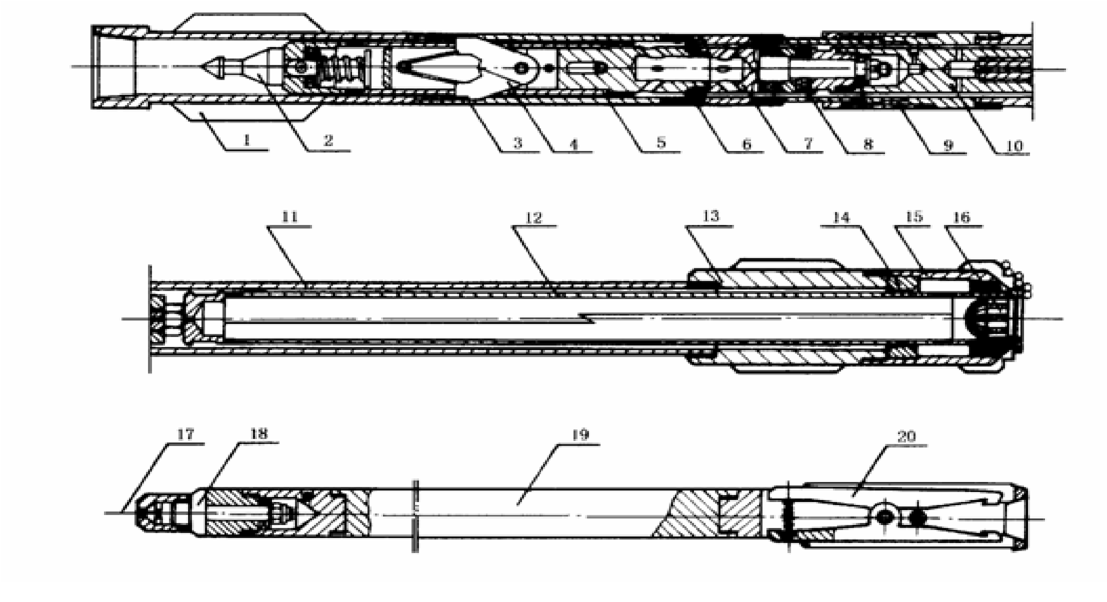

Figure 4.7Structure of wire line coring tools

1.13,14- centering device; 2. bullodog; 3. shell fragment room; 4. shell fragment; 5. gripper receiving tube; 6. suspension hoop; 7. water divide join；8. single acting organization; 9. inside/outside eight sides wrap; 10. inner tube top connector; 11. outer tube; 12. inner tube; 15. bit; 16. blind gripper preventer; 17. steel cable; 18. clip connector; 19. sinke bar; 20. fishhook
Source: Zhao Qingbo, 1999.

The CBM wire line coring technology is developing fast in China. The typical wire line coring tools in China mainly include MS-215，MS-215B，SQX-178，SQM-, S95 [24~28].

As early as at the beginning of the 1990's, the MS-215 wire line coring tool was used in the Liulin pilot zone successfully. This coring tool, with core diameter up to 70 mm, uses dual functional covert core catcher and ladder advance coring bit, enhances the core recovery by averagely over 90%. It uses semi-closed core tube, which accelerate the core tube deviating speed (5 min~10 min) and avoids dislocation of the loose coal core, and finally helps to keep the original coal core condition. The features are: shot pulling out time (about 8 min~10 min) and alarm function of position reaching and core blocking, and these features basically satisfies CBM Coring [25]. Afterward, it is innovated to MS-215B which has better functions [26].

In 1979, SQX-178 Type wire line coring tool was used successfully in Proven Well Group of Well Jinshi 1 in Shanxi Province, and the average core recovery rate there was about 90%, and the technique was awarded national patent [30].

In 2000, the SQM-1 wire line coal coring tools and the ancillary equipments applicable to oil rig equipment and conventional drilling string, were developed. It was successful in testing and application in several wells. Of the total coring 179 barrel times with total coring footage of 243.16 m and core length of 219.55 m, the average core recovery was up to 91.1%; seam footage was 112.08 m and coal core recovery was 87.7%; it took 8 minutes~20 minutes to lift coal cores out of tube and put in can; the coal cores from semi- closed tube kept good form; coring and normal drilling adopted the same set of drill pipes. It satisfied all conditions the CBM coring operation requires [27].

In addition，the coring tool of S95 type is widely used in Yun Gui Altiplano. The diameter of the core drill is short, and the diameter of the coal core is 6.4 centimeters which can meet the requirement of the analysis to coal-bed. The whole drilling equipment is specially fit to the areas with worse situations in traffic and landscape because it is smaller than that used in petroleum industry [28,29].

CBM coring is the best reliable and straight method to obtain the detailed stratum character. It is the basic data source to the production design of CBM and it is important in CBM exploit. A series of wire line coring technology invented in practice by us has met the demand of CBM exploration.

4.2.3.3. The Application Analysis of Completion Technology in China

The methane flows to the bottom hole through the cracks after desorption from the surface of the coal when the pressure drops to a certain point. If the pores and cracks are damaged, the damage is even worse than that of the conventional reservoir. Not only the seeping channel is damaged but also the desorption effect is affected. Several factors in the well completion should be considered such as the damage to the bottom hole, the communication of well and cracks, the stimulation job and the cost. Thus effective completion technology should be adapted to CBM wells and the completion effect will affect the later dewatering. Like other drilling techniques, the completion of CBM wells is developed on the basis of the regular wells. In order to develop the CBM in an economical way, some tests were conducted, such as barefoot completion, case completion and barefoot cave completion [30,31].

1) Barefoot completion.

With this completion method, the drilling bit reaches the place above the coal seam before the casing is lowered down. The pay interval is filled with gravel or kept bare after the casing is put down. It is the most basic and simplest completion method with the lowest cost. The sidewall stability is rather low. The coal-bed collapse has negative effect on the stimulation and it may result in accident while the condition of well-control is decreased. It is easy to be clogged by coal dust if it is filled with gravel for the purpose of stabilization of the wellbore. A more efficient barefoot completion technology is well developed and produces good effects. In order to prevent coal dust, a liner pipe with holes was put down to the bare interval. This kind of completion method is not widely used in China because it is suitable to the single coal bed or the coal beds not far from each other and it can obtain the single production in the areas with high permeability.

2) Casing completion.

It is a completion technology after perforation and slotting in the case. It can keep the wellbore stable and efficiently separates the coal beds and facilitates the later stimulation. The output of methane and water should be forecasted, in order to choose right dewatering equipment and the size of cases. The technology is in great adaptability especially in the wells penetrating in several coal beds or that needs stimulation. And it can avoid many problems in barefoot completion. Casing completion is mature and easy to operate. It is the main completion model in western coal-bearing basins in US and the main completion method in CBM exploration and development in China.

3) Barefoot cave completion.

The collapse of barefoot interval is artificially made to form a big cave. The basic procedure is as follows: a. gas or gas-water injection; b. pressure maintenance; c. pressure drop. Repeat the three steps until the completion purpose is achieved. The porosity is increased because the coal bed is destroyed by tensional fracture and shearing when the cave is formed. The damage made by drilling fluid and completion fluid to coal bed (See Figure 4.8) is decreased if the damaged zone disappears because of the enlarged wellbore diameter [32].In China, caves completion had been tested in Shanxi, Jiangxi, Hebei and Henan provinces, but the results of these experiments were as good as expected.

Qushi 1# in Fengcheng mines of Jiangxi Province is completed with barefoot cave completion, and the completion depth is 1,037.89 m with the burial depth of 962.95 m~966.4 m, thickness of the coal seam is 3.45 m and angle of the slope is 13 degree, bags of the well is 79.49 m deep and the largest cave radius is 2.39 m. At the top of the seam is sand, shale broken belt, and it inter-collapses seriously and it is difficult to be treated in the process of drilling. It takes 221 d to make the cave. Because of the poor coal physical property, the measured permeability is 0.04×10^{-3} μm^2 and skin factor is 0.31 by the way of injection-pressure drop. Despite the elimination of coal pollution, gas production is very low and the maximum stable yield can be 200 m^3 /d. The results of Tang 5# and Jiaozuo 13 # were not noticeable [33].

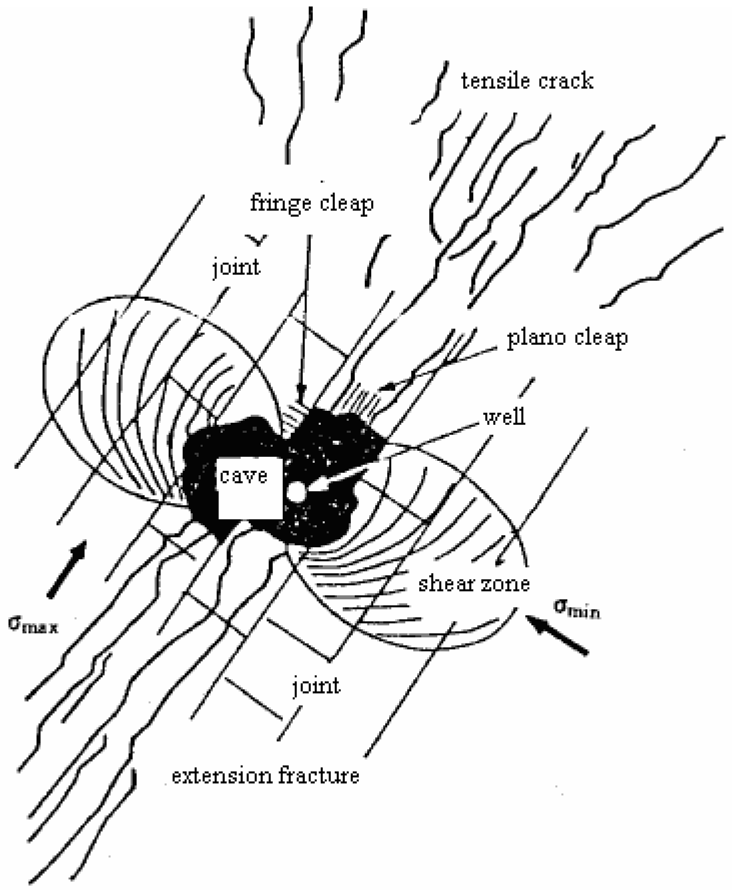

Figure 4.8 Conceptional models of cracks made by nature and barefoot cave completion

Sg-3 wells of Ordos Basin in eastern Shanxi region was completed in Taiyuan 485 m~488 m group. The initial daily gas production of the well was 20,000 m^3 and daily water output was 40 m^3. Permeability of the seam is 32×10^{-3} μm^2. Because of the poor roof deck conditions, gas production declines seriously. And at the later stage, the water output is larger than that of gas, the analysis indicates that water from the top floor and base plate of sandstone enters the wellbore [30].

From China's caves completion test results and from international experiences, we understand the following: caves completion cannot be used in low permeability coal seam or in thin coal bed; caves completion is not suitable for coal bed where coal bed sealing gland is in poor conditions, the roof and base plate mud shale is thin and sealing gland to water layer is poor. It shows that the cave completion can only be used in high pressure, high permeability areas of good sealing conditions, good coal properties, high gas content and gas saturation. Most coal bed in China is with low permeability, such completion method is not yet a success.

Based on the analysis above, we know that most of the coal beds in China have low permeability and low pressure. Except for casing completion, other completion methods are not so popular. When the production well is a multi-branched well, in the vertical segment, casing completion should be applied, and in horizontal segment, open hole completion should be applied [34~37].

4.2.3.4. Analysis of Cementing Technique Application in China

The cementing of CBM well affects the service life of the well and is important to the successful implement of sequent work, and it also affects the yield of the well. The cementing is particularly important to the well with low potential but long-term stable yield. Generally, CBM wells are not so deep, and their depth ranges from 300 m to 1500 m. Temperature, pressure of earth and the cement of coal seam are all low. So, in the coal seam, circulation loss and borehole wall sloughing often happen. All these make serious desquamation in seam segment possible which enlarges well diameter and causes leakage while cementing. And as a result, the hydrating reaction of cement develops slowly and slurry is unstable. It is also possible for the cementing fluid to damage the reservoir. According to the practice of China and international experiences, on the basis of ensuring cementing quality, in order to achieve balance near wellbore area and decline the damage to coal seam, we can control the density of cement and the cement top. The following measure can be used [36~42]:

1) The expanded center micro-pearl low density cement well cementation technology

Low density cement (about 1.34 g/cm^3) means the density is lower than the density of conventional cement (1.85 g/cm^3) used in oil and gas wells, and its application is to reduce the pressure of the coal seam. The key of this technology is how to choose the compound of the cement. According to different low density materials, the low density cement can be divided as: expanded center micro-pearl low density cement, coal ash cement, forth cement, gas charging cement and so on. The first and the second low density cement are cement with solid reducing density material added when making up cement. The other two kinds of cement have addictives of foaming agent or air. The previous method can achieve harder cement and can be conducted easily with low cost.

The expanded center micro-pearl low density cement is produced by adding expanded center micro-pearl, fluid loss control agent, freezing-point adjusting agent and reinforcing agent into normal cement. The expanded center micro-pearl is a sphere, which is bottletight, minute and light in mass. When it is added into cement, the density of cement can depressed to 1.20 g/cm^3~1.50 g/cm^3.

2) The technology to control cement top

In order to decline the hydrostatic pressure of the cement column and to reduce the damage to the coal seam, it is useful to control cement top. Generally, it is to make the pressure of cement column equal to the pressure of coal seam. To control cement top is to appropriately select the density of cement. This well cementation technology is applicable to the most coal seam in China.

3) The technology of many-staged injecting cement

This technology is to decompress the pressure caused by well cementation cement to the fixative normal cement to lower the pressure of coal seam, and the pressure equilibrium well cementation near wellbore area can also be achieved. In this technology, cement can be pumped through duplex pump or multi-staged pump.

4) The reeling coal seam well cementation technology

The reeling coal seam cementation technology is the most effective technology for protecting coal seam. In this technology, the reeling coal seam cementation tools are fixed in the main coal seam. When the cement is injected and reaches the bottom of coal seam, the cement will enter the tubing guide through reeling coal seam cementation tools, and then, the cement will go into the annulus space in the top of the coal seam. The cement will not touch coal seam, and so there is no chance to damage coal seam. What's more, there is no cement mantle between coal seam and reeling coal seam casing, and thus the perforating resistance can be reduced, the depth of penetration can be further, which is beneficial to the sequent working.

During the CBM development course in China, the first three well cementation technologies are commonly used. The reeling coal seam well cementation technology is reported in foreign countries, but it is not applied in China. In all of these technologies, the expanded center micro-pearl low density cement well cementation technology is the most successful one in the CBM development indutry in China.

4.2.4. Development Trend of the Main Chinese CBM Drilling Techonology

The CBM drilling technology in China is developed on the basis of common oil and gas well drilling technology. Through the development of 20 years, a series of mature and reasonable technologies have been generated in China and the research in the technology depends on the actual features of the coal seams in China, and absorbing the experience of other countries.

First, recently, in China, most of the CBM wells are vertical well. In order to reduce the damage to coal seam, air, free water, low-solid mud and lay free drilling fluid have been used in drilling. Other technologies have also been tested, such as multi-branched well and cluster well drilling technology. Although the applications of these technologies are limited, and the application history in CBM is short and the technique need further innovation. But their advantages are obvious, and when the technology becomes mature, these technologies would have a promising future in fitted areas. Additionally, the features of coal seams in China are similar with Australia's, and in the future, the MRD and fixed radius drilling system could be applied in China.

Second, the CBM coring technology mainly focuses on wire line coring. This technology is mature, economical and reliable, and can meet the demands of CBM development in coming years. However, if the cost could be cut down, pressure coring technology and rapid desorption test technology should be widely used.

Third, through several years' practice, casing well completion is the most applicable one in China. This technology is mature, reliable and is beneficial to the work following, and for this reason it has become the key well completion technology in China. We should continue the exploration on open hole cave well completion technology and do research on compound well completion technology in multi-coalbed areas.

Fourth, it is important to reduce the damage to coal seam during the course of well cementation. In China, the main well cementation technologies are low density cement technology, control cementing top technology and many-staged injecting cementing technology. The results of these technologies are satisfactory. But the reeling coal seam well cementation technology, which is more effective, has not yet been used in China, and thus it is an attractive technology in the future in China.

4.3. Overview and Prediction of Key Production Technology

CBM production technology has its own features and the study of them will lay a strong foundation for efficient and sustainable CBM development. Exploration technology is presented in this part. First, two kinds of key modes are summarized, and then the draining for gas production and the pinnate horizontal well technology are mainly introduced, and finally, draining technology is briefly summarized.

4.3.1. Technology Status in the Production of CBM

Two techniques are used in the exploitation of CBM: underground production and surface production. In virtue of the working face and the laneway in the mine, underground production is operated inside the mine, in the working area and the derelict mine. The surface production method is mainly adopted in the countries with developed CBM industry [43]. As for the surface extraction, vertical well and directional well technologies are used to exploit the CBM in situ. The pressure release and desorption of CBM determines the surface determines the choice of surface production technology [44].

4.3.1.1. The Status of Water Draining Technology

There are three flowing stages for the liquid in the coal bed: single-phase; unsaturated single-phase; two-phase flow. The above three stages are shown in Figure 4.9 [45].

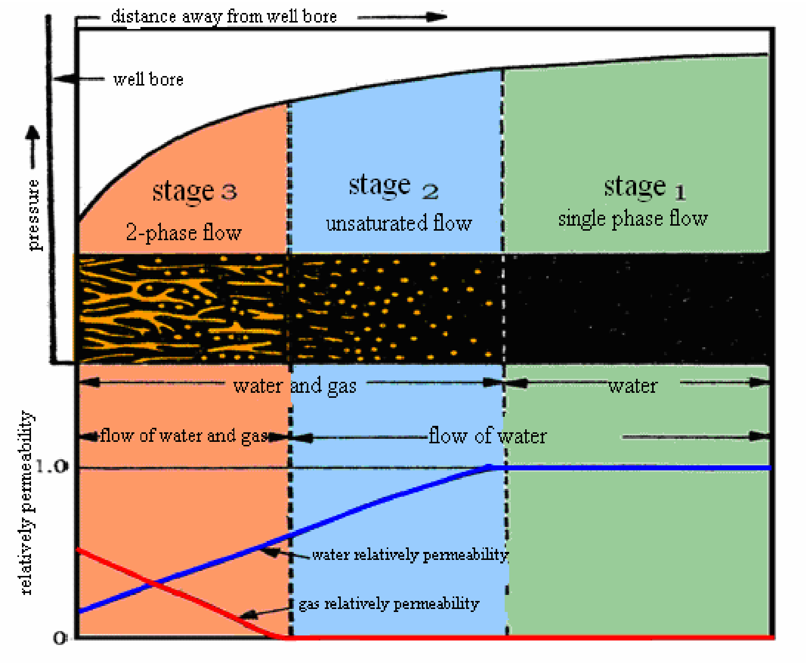

Figure 4.9 CBM underground flow rule (Xuwei, 2001.)

Determined by the production mechanism of CBM, water should be drained to the largest extent while producing CBM. Not only the coal bed pressure falls, but also the saturation of water drops. So the permeability of CBM rises, and the migration of CBM through the coal-bed cracks towards wellbore is accelerated, and as a result, the output of CBM in a wellhole increases. Water production and methane production experience three stages: pressure dropping; steady production; CBM production drop [46].

The law of CBM and water production is shown in Figure 4.10. Draining is needed in the whole process, and the output of CBM first rises and then drops, which is different from the production of regular natural gas.

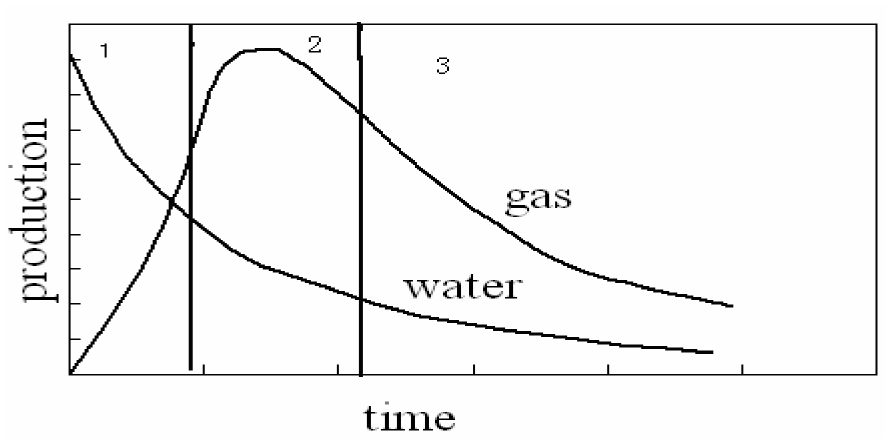

Figure 4.10 Law of CBM and water production (Xuwei, 2001.)

Briefly speaking, water is pumped from tubes and CBM is produced from cases. So the pumping is necessary and other surface technology is the combination of pumping unit and natural gas production technology used in petroleum industry and some improvements are necessary to adapt it to coal seams [47].

There are many water draining methods for CBM production both in China and abroad, including sucker rod pump, electric submersible pump, rotary screw pump, gas lift, hydraulic jet pump, foam bubble method and pipe string optimization and so on. The former three methods are widely used in China. A lot of factors should be considered to choose the pumps, including productivity, well depth, well structure, output of water, formation sand production, the ability of the draining equipment.

4.3.1.2. The Status of Pinnate Horizontal Well Technology

Developed on the basis of regular horizontal well and multi-branched well drilling technology, directional pinnate horizontal well technology, depending on the coal seam geological conditions, is an integration of drilling, completion and stimulation. The pinnate branches are formed by drilling from the surface to the kick off point and then drilling is directioned to small curvatures to drill through the target. In order to cut down the cost and meet the different needs, there are different well spacing patterns which are shown in Figure 4.11 [48]. In addition, it has been used to solve the problems of low bottomhole pressure to improve the recovery and this is the advantage of the technology.

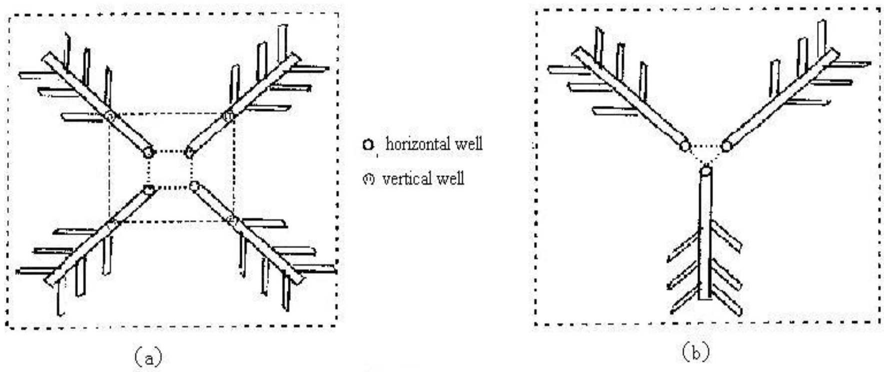

Figure 4.11 Well pattern of the multi-branch horizontal CBM well (Zhangna, 2007)

4.3.2. Analysis of Major CBM Production Technology

4.3.2.1. Analysis to the Application Status of Draining Technology

There are several requirements for draining-for-methane technology: a. high rate of liquid delivery and resistance to well interference; b. decreased bottom hole flowing pressure and the fluid entry of the equipment positioned under the coal bed; c. some measures adopted to prevent coal breeze. Every draining method and its application will be introduced one by one.

1) Sucker rod pump

The technology is maturely used in CBM production. The main equipment is tubing pump which is pulled up and down in the wellbore by the beam. The fluid is allowed to flow up by the valve. The water is piped to the header tank and then moved away by tank cars to treatment system.

a. Selection of pumping unit

The maximum tonnage should be met under the given stroke, frequency and the depth of fluid. At the same time, the maximum loading of the suspension center and the torque rating of the reducing gear box should be within its value. Working parameters should be adjusted in time to meet the needs of continuous and steady fluid deduction. In order to avoid the stirring to coal bed, long stroke pumping unit should be chosen.

b. Selection of tubing pump

Tubing pump is easily affected by gas and sand which cause damage to the pump and reduces the pumping efficiency. It can form gas lock which will prevent the pump from pumping fluid when the impact of gas is very severe. In the early days of production, because of the effects of fracturing sand, coal breeze and the well deviation, the term of pump inspection is very short and the known causes are as follows: rod break and the plunger freeze-in. tubing pump suitable for the well, whose water output is below 100 m^3 and expected deviation and sand flow. Downhole should be specially designed for the wells with high methane output and serious sand flow. It is proved that that kind of pump with ring plunger which can be put in the tube and to the lowest producing layer is economical and efficient [49].

c. The diagnosis technology to pumping wells

The familiar diagnosis technologies to liquid producing well include the following: liquid testing to analyze the liquid, basic sediment and water content; static liquid level test to learn about the changes of the reservoir static pressure; dynamic liquid level test to learn about the ability of feeding flow; measuring dynamometer diagram to measure the load of the rod in order to analyze the circumstances of pump and other parameters.

2) Rotary screw pump and electric submersible pump

Rotary pump is a kind of rod pump driven by a rotary rod. It mainly consists of driving equipment, rod and pump. It is seldom used in CBM production in China, and the introduction is omitted here.

The applicability of electric submersible pump is greater. It is mainly used in the following circumstances such as deviation wells, high output of water. The velocity of electrical motor and the pump is controlled by the surface equipment through cable. The reasonable depth of electric submersible pump is 1,800 meter with the delivery capacity of about 100 m^3. The motor is cooled down while the fluid flowing through the centrifugal pump. So the pump should be fixed above the perforated interval with the submergence depth of over 50 meters. The velocity range of electric submersible pump is high. The gas/water separation is easily done and the negative effects of sand are less. Its disadvantage is its high cost.

3) Gas lifting

No introduction of gas lifting is seen in China. It is much less popular than the former three pumps, but it is a popular artificial lifting in the areas without electricity or of high electricity cost.

The gas lift system consists of a series of working barrel and gas lift valves. The common model is injecting by case and producing by tube. And a reverse process is also possible.

Few surface equipments of gas lift are used and the pipe string is simply designed. But the technical demanding is high. Compressed CBM is often used as the injection resource. The impact of sand and mechanism is limited and is used to deal with solid grains. It fits the heavy draining load at early production. It is economical to use gas lift in the early days of production proved in the Black Warrior basin. In the later stage, it can be replaced by pumps with low power.

4) Surface equipment for draining

The equipments are as follows: choke, choke seat, gas vacuum pump, gas separator, relieve valve, intelligent flow gage, gas compressor, chemical feed bag, lightning rod ECBM flow and monitoring device.

5) Selection of the draining technology

To use most suitable technology, we should choose the technology and the equipment on the basis of production forecasted by hydrologic geology. The changes of water output of CBM wells are obvious, and the technology should suit the production process perfectly. Maximum water output should be obtained with the lowest bottomhole pressure and it is fine to produce methane as soon as possible.

The choice of draining method depends on a series of analysis including pressure, output of water and methane of a given well. The life and efficiency of the equipment may be shortened if the sensitivities of geology and environment are neglected. Besides the dynamic parameters, other sides should be concluded such as fluid character, sand, scaling, electric supplying, gas resource, the environment of the coal field. The draining technology is shown in Table 4.5 [50].

6) Recovery working system and control system

Study shows that for the production situation of the major CBM fields in china, such as Duangzheng block, Fanzhuang block, Paner block, constant pressure recovery and constant rate recovery are the main working system.

In order to reduce the reservoir injury , we should control the recovery intensity and the velocity of well bore pressure drop .adjusting working system on time in terms of working fluid level .To ensure the stability of CBM production wells and keep sustainable high yield, in the early Gas Recovery , constant pressure recovery is used as the normal production system. The key of the constant pressure recovery technology is its effective control of pressure difference between the bottom hole flowing pressure and the reservoir pressure, appropriately the control of fluid flow rate near the well bore to ensure the normal production of coal dust, other solid particles, water, gas. in the process of recovery, mainly through adjusting water production and wellhead casing bottom hole pressure to control the pressure difference between the bottom hole and reservoir .

Table 4.5 Comparison of draining technology

Item		Best String	Foam Drainage	Air Pumping	Beam-Pumping Rod	Submersible Electric Pump	Jet Pump
Maximum Drainage（$m^3 \cdot d^{-1}$）		100	120	400	70	500	300
Maximum Well Depth/m		2,700	3,500	3,000	2,200	2,700	2,800
Slant Hole		Moderately Applicable	Applicable	Applicable	Inapplicable	Inapplicable	Inapplicable
Surface and Surrounding Conditions		Good	Good for Small Equipment	Good	Good for Large and Heavy Equipment	Good for Small Equipment and High Voltage Electricity	Good if Power Source is Far from the Wellhead
Production Conditions	High Liquid-gas Ratio	Very Good	Very Good	Good	Good for Gas-Liquid Separation	Normally Good but with Sensitivity	Normally Good but with Sensitivity
	Sandy	Good	Good	Good	Poor	<0.5%	Good for Non-mobile Equipment
	Scale Deposit	Good for Chemical anti-scaling	Good if Well Flushing System available	Good for Chemical anti-scaling	Poor for Chemical anti-scaling	Good for Chemical anti-scaling	Good for Chemical anti-scaling
	Corrosion	Good for Corrosion Controlling	Good for Corrosion Controlling	Good	Poor because of High H_2S Content	Poor	Good
Design		Easy	Easy	Easy	Easy	More Complicated	More Complicated
Maintenance		Extremely Easy	Very Easy	Very Easy	Easy	Very Easy	Very Easy
Investment		Low	Low	Middle	Middle	High	High

When the CBM production wells reach production peak, in order to control the CBM production effectively, constant rate recovery is a good choice to undertaking normal production.

An the fracturing fluid recovery and liquid drop phase, the intensity of initial recovery should not be too large, flowing back should be smooth and dynamic liquid level smoothly decline. Stepped down flow approach is used to down flow mainly against displacement caused by great fluctuations in the producing pressure drop, so that sand enters. In the critical gas production stage, as the change in flowing near well bore, fluctuation change is clear. To infill level survey at this time is necessary. Taking appropriate control measures according to the actual situation, we should use definite bottom-hole pressure manner to recover CBM, after the production-pressure curves are acquired, constant rate recovery was conducted according to the actual situation [57].

4.3.2.2. The Application Status of Directional Pinnate Horizontal Well

The main mechanisms of the technology conclude as: a. enlarging the drainage area; b. improving flow conductivity; c. reducing the damage to the coal-bed.

The CBM productivity is affected by many parameters. But in some special beds, these parameters are interlinked. Generally speaking, the lower the hot evolvement is, the lower the coal rank is and the more favoured the physical property of coal bed is.

The velocity of desorption mainly depends on the absorption time constant in vertical well production. The saturation of gas in debris is determined by different isothermal adsorption line which is determined by different Langmuir constant. The production is restricted by the characteristics of gas resource which is determined by the above parameters. The characteristics of CBM production and transportation are determined by the property of the characteristics of the stratum such as the pressure, permeability and the flow performance of the fluid. Whether the above parameter is the same as that in vertical wells needs measurable analysis. In addition, the following factors should also be considered such as the length of the branches, the thickness of suitable coal bed and so on.

4.3.3. The Analysis of the Development Trend of the Production Technology

4.3.3.1. The Forecast to the Development Trend of Draining Technology

There are several features in the CBM surface production such as the lower depth, light load, great changes in the output of water in different stages. Pumping unit as the surface rigging is widely and fully used in CBM production. But the operation is inconvenient and the energy consumption is severe. In order to fully use the energy and save electricity, it is necessary to set a series of standard operation to pumping unit. We can believe that with the spread of use of pumping unit, some further improvement will be made and a series of standard systems will be formed. In addition, further improvement on the usage of preventing sanding in and anti-erosion to rod pump will be made. As to electric submersible pump, it needs further study to cut the high cost of well repairing and itself.

China has no standards to regulate CBM production process. And the process of flowing well and regular well is basically used. The structures and functions of the processes used by different CBM production companies are different. This is also one of the problems need to be settled in drainage technology.

4.3.3.2. The Development Trend Forecast of Pinnate Horizontal Well Technology

The production features of pinnate multi-branched well can be generalized as: a. pinnate multi-branched well is a dual-well system, which has larger flush-flow area different from normal wells; b. water discharge and gas production are going simultaneously, and the maximum yield will appear immediately; c. it can continuously produce for about 2~4 years in one coal seam; d. when this technology is used, it is not necessary to implement hydraulic fracture in multi-seam; e. the technology has little impact on environment. It is helpful to protect the reservoirs and environment.

The coal seams which are fit for pinnate multi-branched well should have the following properties: adequate thickness, sustained distribution, complete structure, higher coal rank and hard texture. Some coal seams are not fit for vertical wells, such as areas with no anticline coping structure, of low permeability, and mountain areas. It is not suitable for the coal seams with high porosity or inter bed.

Because most of the coal seams in China have low permeability, and usually produce with vertical wells, and so the impacts from well canister are limited. So far, the technology of pinnate multi-branched well is not so mature in the field of CBM's development. We should integrate the technology into directional well, multi-branched well, horizontal well, well path control and reservoir protection technology, learn from the experiences of other countries, apply these technologies practically, conduct engineering study and experiments, and gradually accumulate experiences. So we can finally develop a series of technologies for pinnate multi-branched wells that are fit for coal seams in China [51].

4.3.4. Technology of Produced Water Treatment

A series of problems are caused by the development of CBM. The most serious one is discharging of produced water. So, we must pay attention to the treatment and comprehensive utilization of the produced water [52]. The produced water has different properties in different area, the kinds of contaminant and amount also varies a lot, so we should use diversified methods to treat them. Through monitoring and research of the water produced, we found that the main contaminants include suspended pollutant, chloride ion, fluoride, heavy metal [53].

1) Elimination of suspended pollutant in produced water

Conglomerating, deposition and filtering are required process in the purification of suspended pollutant. The typical technological process is shown as follows (See Figure 4.12);

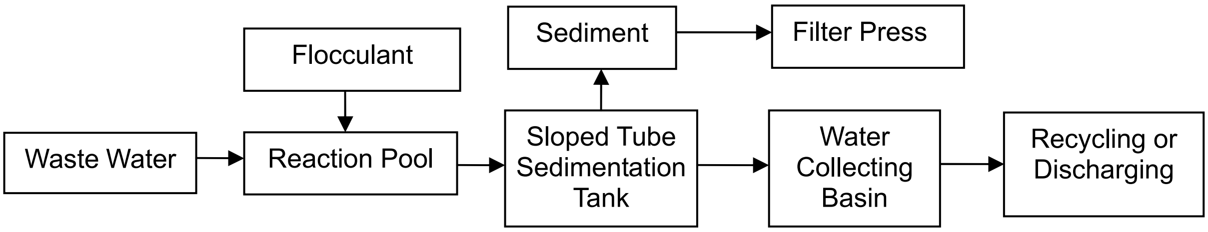

Figure 4.12 Typical technologies for suspended pollutant treatment
Source: Liang Xiongbing, Cheng Shenggao, 2006.

In the treatment process mentioned above, the choice of coagulant is very important. The mostly used coagulant now is polymer aluminium. HPAM can also be used as coagulant, whose processing is also effective. In the state of Alabama, the produced water with mineralization degree lower than 2000 mg/L, was treated through deposition, filtration and then discharged into the near river. Most of the water was discharged into Black Warrior River and its branch rivers. In this area, a monitoring system of about 240 km long has been established. According to the monitoring result, the discharged water has little impact on the water quality and animals in the river when the produced water is treated.

2) Waste water with hypersalinity and high chloride ion

Direct discharging of the water with hypersalinity and high chloride ion causes acute impacts on the water and environment. It can also cause the slab and salting of soil. So, the hypersalinity and high chloride ion water must be treated before discharged [54].

a. Anti-penetration treatment

This technology is for the water which has high degree of mineralization and permanent hardness. The desalting rate can reach 91%, de-hardening rate can reach 95%. This method has a lot of advantages: small volume of installation, successive operation, and steady water quality. The circuit is shown as follows (See Figure 4.13);

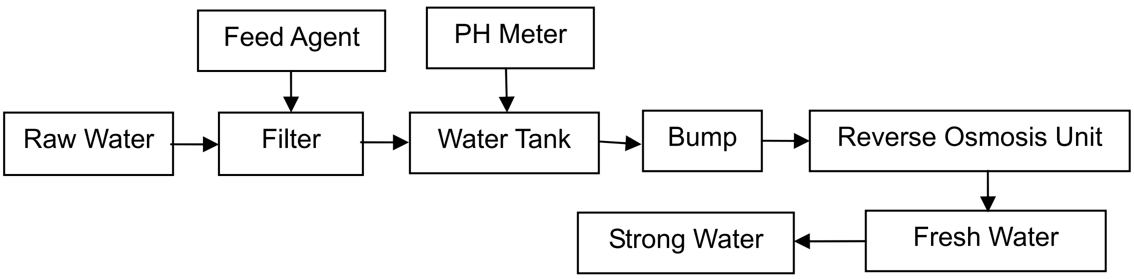

Figure 4.13 Processes for Salty Water Treatment with Reverse Osmosis Unit
Source: Liang Xiongbing, Cheng Shenggao, 2006.

b. Surface evaporation

Some measures, such as anti-penetration and distillation is costly, and thus surface evaporation is frequently used. The company of Taurus use surface evaporation to treat produced water from CBM well. This method may cause pollution to the environment, such as the vaporization and percolation of hydrogen sulphide. For that reason, governmental support is essential before building evaporation pool.

c. Reinjection to underground

This method is suitable for the salty water disposal produced with CBM. The produced water was re-injected to the formation. The sandrock formation is the most suitable for re-injection. This kind of technology has been applied in the United States and Canada.

3) Produced water with fluoride

The methods to treat produced water with fluoride include: a. lime cream deposition; b. aluminium salt coagulation; c. ion exchange; d. electric coagulation.

4.4. Present Situation and Outlook of Key Stimulation Technology

CBM has many characters: lower elastic modulus than sandstone or limestone; high compressibility coefficient and low reservoir pressure; with both gas and water content; easy to be damaged; with many nature fractures. So it is not easy to be exploited by conventional methods, and stimulation method is needed. At present, the stimulation technology used in CBM in the world include: fracturing, gas displacement and multi-branched well technology. Most widely used technology is fracturing for its low cost and good effect. But in some coal beds, fracturing is not as good as expected, and gas displacement or multi-branched well technology can take its place.

4.4.1. The Present Situation of Key Stimulation Technology in China and Abroad

4.4.1.1. The Present Situation of Key Stimulation Technology Abroad

CBM Fracturing, evolved from conventional oil reservoir fracturing, is widely used in CBM exploitation all around the world, and has brought about remarkable stimulation effects [55]. The research in CBM exploiting initiated in US and the technology is comparatively mature there. Among the 14,000 CBM wells, 90% were stimulated by hydraulic fracturing. Fracturing creates many extended cracks. The output was improved by five to twenty times. Most coal in Canada is low rank coal, with characteristics of low gas content, tight, low formation pressure and low permeability, therefore conventional methods are not applicable. Canada developed high flow rate N_2 foam fracturing technology adapted to the CBM resource conditions and it has successful experiences of shallow gas development. Australia studied coal bed stress to design fracture simulation, a directional canal was cut and a hole was shoot directionally before fracturing to release the stress. As a gas displacement technology, CO_2 and N_2 injecting was first used in the United States to enhance the recovery, but it is not widely used in other countries. Multi-branched well technology was first used in the United States too, and this well-developed technology enhances the recovery dramatically [56].

4.4.1.2. The Present Situation of Key Stimulation Technology in China

The permeability of coal beds in China is 3 or 4 order of magnitude lower than that in the US, and low permeability makes it impossible to form large range of desorption- diffusion- filtration in the radius of wells [57]. At the same time, the CBM anisotropy in China is serious, which causes limited wellbore impact on the area around and makes the integrally depressurizing of well network difficult. Besides, the high rank coal accounts for 27.6% of total CBM reservoir in China. Theoretically, these coal beds don’t have the producing ability, but in fact, production from the anthracitic coal has been obtained from the wells and a small testing area in Qinshui Basin. This fact tells us that high rank coal is an important target of CBM exploitation, but low permeability and difficulty in desorption are still blocking the exploitation of high rank CBM.

At present, hydraulic fracture technology is the most common and effective simulation method in China, and most CBM wells here need to be fractured. Previous experiences show that fracturing should be conducted in the stable coal beds with thin coal layer (less than o.8m), less burial depth, good physical properties, developed cracks, high gas content (soft coal or semi bituminous coal). Method selection depends on the coal temperature, pressure and physical properties. Most of CBM wells in China use water fracturing, with a few using foam, and gelled fracturing. The gelled fracturing suits high permeability coal layer while water fracturing suits low permeability coal layer. Gelled fracturing is used in loose well network while water fracturing is used in dense well network. Foam fracture fluid can decrease the permeability effectively, and it is widely used in the CBM production because it has the merits of seduced drainage, low damage to the coal bed, pretended fracture fluid.

Gas displacement in CBM exploitation can be well used in the coal seams with high pressure, middle thickness, and low temperature. Gas displacement is not widely used because the technology is immature, and the key problem is where to get the gas.

Multi-branched well technology is considered as a new stimulation technology with efficiency at present, and this technology relates to many aspects such as drilling, exploitation and reservoir improvement. It costs much and has high risk so it is only used in some areas in China. The multi-branched well is effective to low rank coal, but in China most of the coal is of high or middle rank.

4.4.2. The Application Situation of Fracturing, Gas Displacement and Multi-Branched Well Technology in China

4.4.2.1. The Application of Key Fracturing

The intrinsic permeability of coal seams is relatively low, and therefore the permeability should be improved. Fracturing is just one of the right stimulation measures. There are two types of fracturing: hydraulic fracturing and high energy gas fracturing.

1) Hydraulic fracturing

The peculiarity of coal beds

Coal bed has different mechanical properties different from those of conventional reservoirs. Compared with conventional reservoirs, coal beds have lower modulus of elasticity, higher Poisson ratio, special dual-pore configuration, mature clap, higher aeolotropism, and the generation, accumulation, transportation and development mechanism of CBM are different from those of conventional gas. CBM is restored in the form of adsorption, and its generation is a process of adsorption- diffusion- filtration.

The difference between coal fracture and oil layer fracture

Coal is frangible, so it is easy to generate much coal dust for the abrading and shearing effect of fracture fluid during fracturing. The coal dust has some negative effect such as raising the fracturing pressure, affecting the result by blocking the flow matrix and increasing the flowing difficulties in later stage. And the coal bed has low permeability that it may be harmed by the fracture fluid. So the coal dust should be reduced during operation, and there should be less fluid waste, and have good ability of gel out and flow back.

Key problem in coal bed fracturing

There is no sufficient research in coal bed cracking mechanism, in characteristics of the seam, in character of crack propagation, the choice and usage of fracture fluid. Research in the low-damage fracturing materials and in fluid loss agent to satisfy need of the long, wide fracture is still going on. Simulation and diagnosis of complex cracks is still being studied. There is software used in oil reservoir to simulate the coal fracturing, but more amending work needs to be done. Assessing methods and techniques used before and after fracturing.

Choice of fracture fluid

The fracturing fluids used in coal beds have to meet some requirements of coal beds. They should have good capacity of prop pant carrying and width generation, good anti-filtration property, easy to gel out and flow back, less damage to the reservoir. The fracture fluid used now is gel, active of free water, foam and so on. There are two types of gel fracture fluids, cross linked gel and linear gel. The cross linked gel is especially effective to high fluid loss coal layer and is more widely used in China [59]; active or free water fracture fluid has many merits such as low cost, low damage to the permeability, simple making process, and thus it is widely used in the United States and China. The foam fracture fluid is a kind of compound of N_2 or CO_2 dispersed in the soul fluid or polymer gelled fluid in gaseous state. It has the characteristics of less harm, good flow back ability, less filtration, high efficiency, high viscosity, and high carrying capacity, and it suits seams of low pressure, low permeability, extremely low permeability, and water sensibility. Each fracture fluid suits different layer, but the destination of each one is to carry the prop pant into the coal bed, to form high flow conductivity, decrease the damage to bottom and enhance the production finally.

Fracture addictives and their selection

The additives include densifier, cross linker, pH conditioner [59]. Densifier can decrease the pollution and protect the coal bed. The function of cross linker is to make the densifier molecule in densified liquor to form long chain, to enhance the viscosity quickly of the liquor to raise its capacity in fracture initiation and silt carrying. The aim is to assure the applicability of the cracking liquor to coal bed, debase the damage to coal bed, and improve the cracking liquor's capacity of silt carrying. The aim of pH conditioner is to assure the applicability of the cracking liquor to coal bed, debase the damage to coal bed, and improve the cracking liquor's capacity of silt carrying.

Choice of propping agent

It is also very important to choose propping agent in cracking, for it is the key part of boosting FCD. The intensity, cost, circumfluence and invading stratum are all factors we should consider while choosing propping agents. The ideal propping agent should possess characteristics of low density, high intensity and high round ball degree, and inertness in high temperature water, etc. Presently, we often use quartz, resin coated gravel as propping agents. The popular standard of quartz is 40~70 silty sand, 20~40 medium sand and 12~20 harsh sand. There are four assembled ways for sand fracture: silty sand plus medium sand plus harsh sand, silty sand plus harsh sand, medium sand plus harsh sand, harsh sand. Sometimes, there is no sand in it and that will cut down cost and avoid propping agent circumfluence. Its effect is better if applied in the area where the local stress is relatively low (take shallow coal for example) and the fracture can keep open with quite good effect of cracking [60]. The advantages and disadvantages of different kinds of hydraulic fracture are summarized in Table 4.6:

Table 4.6 comparison between various hydraulic fractures

Fracturing method	Cost	Coal seam damage degree	Proppant placenment effect	Propping length
Water fracturing	Low	Low	Poor	Short
Linear gelled fracturing	Middle	High	Moderate	Moderate
Cross-linking gelled fracturing	Middle	High	Best	Longest
Foam fracturing	High	Low	Good	Long

Source: Zhao Qingbo, 1998.

2) High-energy gas fracture

In the view of the development of CBM exploitation, in order to boost the output of single well, we should seek for effective, simple and convenient method with low cost besides water fracture technology and horizontal well drilling. The study and application of high-energy gas fracture technology in China has lasted for 10 years, and we also have developed the technology of open hole fracturing bullet, shelly bullet, caseless shaped charge and multi deep penetrating perforation, and liquid explosion. This method is mainly applied in removing choke near the wellbore because of its short radius. We should improve the high-energy gas fracture technology to meet the requirement of CBM stimulation based on the characters of CBM well.

3) Fracture evaluation technology

The effect of CBM well fracture evaluation technology is different from that of conventional oil gas well because we can only analyze the fracture effect by measure its semi length and flow conductivity. It will be better to use the methods of earth potential, well temperature, micro-earthquake and radioactive tracing. CUCMC got great results in inspecting trial by using the four methods on wells named FZ001, FZ005 and FZ008 [61].

4) Secondary sand adding technology

The way of secondary sand adding technology is to input the sand into the well, then lift the sand proportion artificially to the limit of sand fill, and then stop the sand and infuse fluid ahead after the same process. We can carry through multi-staged sand input by this way and the quantity of sand input depends on specific fracture layers. The application of this technology can connect more natural cleat systems, boost the permeability of coal beds, and increase the output of CBM. Northeast coalfield applied this technology in nine coal-bed fractures out of eleven, resulting in more output [62].

5) Practical application in fracture locale

The first item of Panhe of Qinnan CBM field has 38 producing wells. All use active water gravel input fracture technology and 2 wells are applied with nitrogen foam fracture technology with good effect. From PH1 well, gas output is stabilized between 2000 m^3/d and 2300 m^3/d with the PH1-006 rising from 2300 m^3/d to 3950 m^3/d.Compared with the wells around, its output is increased above three times, and the output of nitrogen foam fracture well is obviously larger than that of active water gravel input fracture well [63].

Experiences from the fields:

First, hydraulic fracturing gives priority to high delivery capacity, which should be moderate. The larger the delivery capacity is, the deeper the crack will be created. Excessive delivery capacity is likely to damage the coping and bottom of coal beds, which makes the cracks unable to extend in coal beds, and it will limit the effect severely because of the relatively smaller fractures. The stratum with large filter loss, complex geology and abnormal pressure should be introduced in the technology of production rise, prop pant concentration reduction and FLA agent to prevent sand falling out.

Second, during fracturing, water fracture fluid is used in shallow single coal bed. In a series of thin coal beds, the pressure of the coal is usually lower than that of single coal bed, and so it is better to use delayed cross linking or foam fracture liquid. In a thick coal bed, it is necessary to form multiple items of composite crack system, and thus it should be infused at a high speed to overcome the high filtrate volume, and delayed cross linking fracture liquid has sound application at this coal bed.

Third, different fracture liquid should be adapted to different propping agents. Gel and foam can take much more sands than water. Rinsing fracture without sand is fit for shallow well, and the fractured crack can be kept widely open with advantages of low cost and no secondary pollution.

4.4.2.2. Application Situation of Multiple Gas Displacement Analysis

Gas displacement is a process to inject gas such as N_2, CO_2 into reservoir, and in fact it is to infuse energy into coal bed, to boosting the CBM output from a single well and to raise extraction ratio by changing pressure conduction and augment diffusion speed. There are two types of gas. Coal is a porous media which owns relatively high residual surface energy in certain quantity. After mixed gas comes into a balanced state, the absorption quantity is lower for every component than single absorption in the same DP. Some adsorbent methane disports, and consequently raise diffusion rate, Darcy velocity and recycle rate after infusion. Different gases have various adsorption abilities because of different acting force between gas molecule and coal. The adsorption ability is decreasing among CO_2, CH_4 and N_2.

From the comparison of 4.14 we can get the conclusion that CO_2 is more effective to displace CH_4 out. CO_2 has many potential advantages compared with N_2. CO_2 is lower in price, smoother in penetration, and it shows better performance in the recycle of coal bed gas.

The mechanisms of infusion of CO_2 and N_2 are different. The adsorption ability of coal to N_2 is lower than to CH_4, so there is no competitive adsorption between N_2 and CH_4. That means N_2 can not push CH_4 out between matrices fractures of coal. But under the same pressure, we can decrease the available DP of CH_4 by infusing N_2. And N_2 can also dispel CH_4 out [64] (See Figure 4.15).

Amoco Co. assimilates the N_2 displacement with the “harrow”, and meanwhile assimilates the CO_2 displacement with the “broom” in labs, because the former can only displace some of the gas, but the later can displace the whole gas.

CUCMC has preceded several producing test after CO_2 injecting with the help of Canadian professor. TL-003, a well of Date Yard well group in South Qinshui basin, was chosen as a test well. By means of injection, of well shutdown (let the CO_2 displace CH_4 properly), of production and of component monitoring, the test is successfully done with the production of 1,200m^3/d [65]. Figure 4.16 are the curves before and after the CO_2 injecting.

From those experiences in China, Gas displacement has good effects in the places with high permeability, high pressure, moderate width and low temperature.

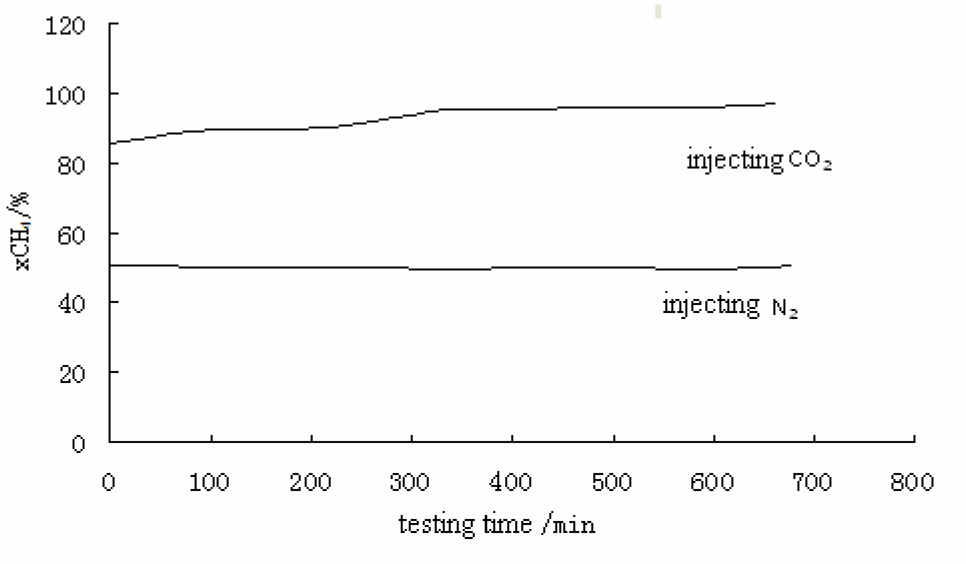

Figure 4.14 Displace CH_4 with CO_2 and N_2 under constant volume
Source: Ma Zhihong, 2001.

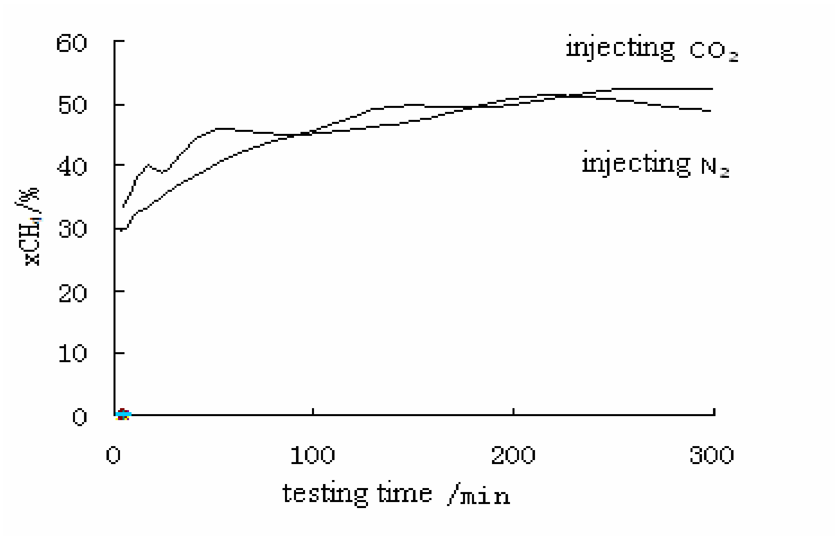

Figure 4.15 Displace CH_4 with CO_2 and N_2 under constant pressure
Source: Ma Zhihong, Guo Yongyi, 2001.

4.4.2.3. The Applicability Analysis of Multi-Branched Well

The branched wellbore can get through more systems of cracks in the coal bed, communicate the crack channels and enlarge the air-leakage area (See Figure 4.17) and increase the static permeability. As a result, the individual-well production rate is enhanced. It is proved that the production of horizontal well is three to ten times of that of vertical wells. It has other advantages such as reducing the number of conventional wells and floor areas, saving pipelines [66].

The pressure in the multi-branched well decreases gradually during production and this pressure drop extends outward from the whole well system. The whole horizontal hole could be taken as the source of formation pressure dropping. Obviously, in multi-branched wells no so-called depressed pressure hopper will occur. This technology could make use of the whole coal seam simultaneously, and the potentiality of the coal bed could be fully displayed.

The first domestic CBM multi branch well named Well DNP02 in Qinshui basin of Shanxi Province was drilled by Orion Energy International Company in Nov. 2004. At beginning, the gas production was 15,000 m^3/d. After 135 days of production and drainage, the CBM production remained steady, with a daily output of 20,000 m^3/d, 20 times of the production of a vertical well. In 2007, a multi-branched well group of 6 wells or 3 sets wells was finished in Panzhuang CBM Area by China CBM Company. At present, all of the 6 wells have been put into production, with an average single well production over 50×10^3 m^3, and some even produce more than 80×10^3 m^3, and the production remain rising.

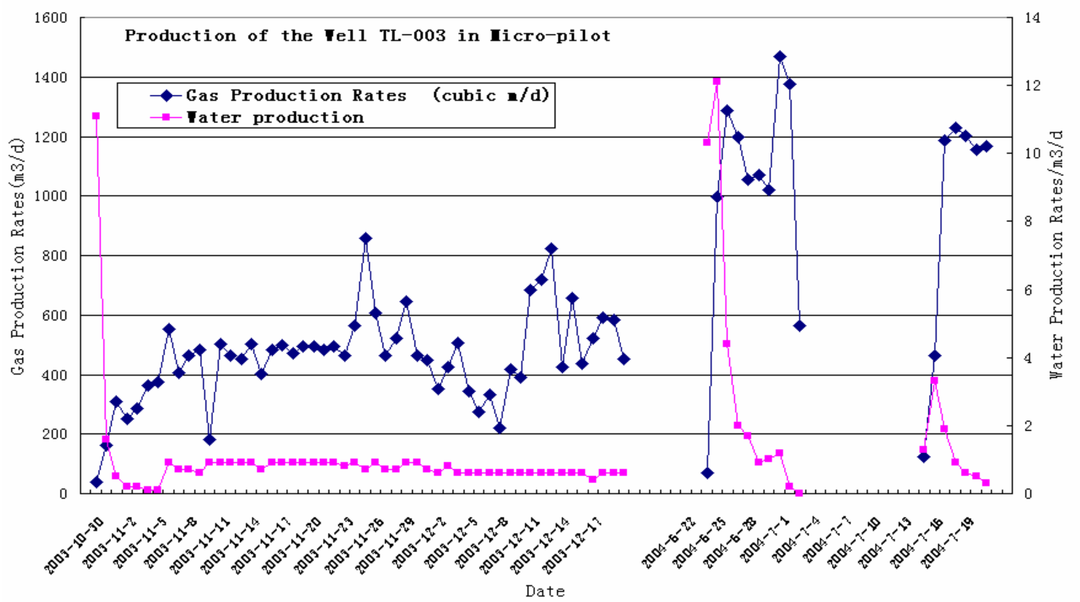

Figure 4.16 Previous curve before and after the CO2 injecting of TL-003
Source: Ye Jianping, 2007.

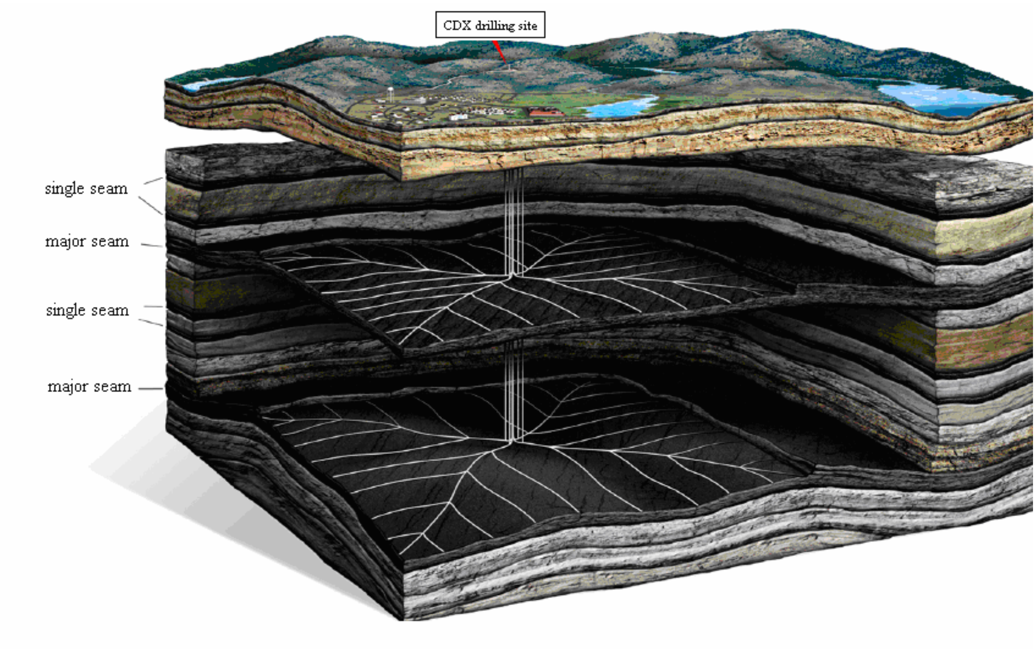

Figure 4.17 Pinnate multi-branched well of CDX

From those experiences, we learn that not all the multi-branched well have expected performance. Multi-branched well can produce good results at the coal bed that has appropriate mechanical features, no fracture zone, not much sand shale, successive and stable distribution at the cross line, no fault or pinching. It functions well at low permeable sub layer and gas-bearing regions.

4.4.3. Demand for Key Technology and Target for Development of Key Stimulation Technology

Stimulation in CBM is very important; we can find some solution from the research on the Chinese CBM:

Fracturing technology is the widely used stimulation method. Because coal is friable and soft, its hole is easy to be blocked by coal dust, propping agent is prone to enter the coal seams, fracture network is complex and fracturing liquid loss is serious and is difficult to flow back, and all the factors above complicate the CBM well fracturing. In the fracturing aspect, the key solutions will be: to strengthen research in mechanism of coal crack, to do research in propping agents with less damaging to coal and in fluid loss control agent, to study CBM fracturing design by hydraulic fracturing simulation software and improve the evaluating technology for before and after fracturing, to study 3-D and full 3-D fracturing design software to optimize single well design, and then optimize the design of the whole block.

As for gas displacement, there are also difficulties. Mechanism of displacement is not very clear and lack of gas resource is a block to ECBM. Through the adsorption - desorption experiments, futrehr research is necessary in competition adsorption-desorption effect and substitution mechanism of multi-dimensional gas in coal. Further study should also goes on to the impacts of different gas on methane dsorption–desorption and the relationship between the replace speed and the adsorption equilibrium pressure, differential pressure of various component gas. The studies mentioned above may result in the development of the software of CBM production by gas injection.

Multi-branched horizontal well technology is a newly developed technology. The several successful wells of this kind in China show remarkable production increase, and have achieved more than expected economic benefits. It is proposed to do further study in stimulation mechanism and output simulation technology, and also the adaptability of the technology. Multi-branched horizontal well technology will be a good choice for CBM development in the future.

4.5. Development Plan Design for CBM Reservoirs

4.5.1. Applicable Technologies for the Exploration and Development of CBM in China

To conclude our discussions above, a series of technologies suitable to the exploration and development of CBM in China are summarized and these technologies are developed based on the conditions of the coal beds in China.

4.5.1.1. Drilling Technology

1) Well style selection

Considering the technical maturity, the vertical well is a preferred style for CBM development in China.

2) Drill fluid selection

In order to control the damage to the reservoir and to protect reservoir, two technologies are recommended: free water drilling technology and air drilling technology. That is, to use air foam and free water as circulating medium to perform under-balanced and near-balanced drilling.

3) Coring method selection

We use the wire line coring as the main way to core. The distinguished features of this technology are high coring speed and high efficiency, without requirements for hoist. It can also core continuously and provide exact gas concentration.

4) Well completion system selection

In Well completion system selection, we should adopt casting cement completion and perforating fracture completion.

5) Cementing method selection

In Cementing method selection, in order to achieve near equilibrium pressure, we can control cement slurry density and cement top to reduce harm to the coal seam while assuring expected cementing performance. According to the practice of Chinese CBM production, we recommend syntactic low-density slurry cementing technology.

4.5.1.2. Recovery Technology

1) Recovery Equipment

The selection of recovery equipment depends largely on well depth, bottom-hole pressure, water content, water velocity, gas flow rate. In Chinese CBM development activities, generally, we choose beam pump, screw pump and electric submersible pump.

2) Recovery System

Commonly-used recovery systems in China are constant pressure recovery and constant terminal rate recovery.

a. Constant pressure Recovery

To ensure the stability of CBM production wells and keep stable yield, constant pressure recovery system is recommended for the early recovery period. Experiences from Chinese CBM block development; a gradual pressure reduction recovery production system is deduced to conduct constant pressure recovery. Recovery rate control principle is: water content is relatively high in early days of production. And we should measure the water depth everyday and adjust delivery capacity timely according to the rate of water decline. After CBM is produced, there is air-fluid two-phase flow in the reservoir, and water production declines with the increase of gas production. Recovery rate should be control according to the changes between gas and water content.

b. Constant terminal rate recovery

When the production of CBM wells reaches peak, constant terminal rate recovery can be used for regular production in order to effectively control the CBM production,.

4.5.1.3. Enhanced Recovery Technique

1) Stimulation selection

Fracturing is the most important stimulation measure out of fracturing, steam injection, multi-branched well technology. Experiences show that stable coal beds with shallow burial depth and thick coal layer are easy for fracturing.

2) Choice of fracturing fluid

Selection of fracturing fluids depends on coal seam temperature, pressure and coal properties. According to the characteristics of the coal seams in China, water-based fracturing fluids are the best choice. In addition, foam fracturing technology can effectively reduce fluid loss and is conducive to fluid flowing back from induced fracture, and all the gel will be broken and drained. It causes limited damage to the seam, and may also be applied to production under appropriate conditions.

4.5.2. Production Prediction of CBM

Production prediction for CBM blocks is the foundation for reasonable development blue print. Based on the analysis of the applicability of China's CBM supporting technology, we uses CBM modules in the commonly-used commercial Eclipse software to predict the production of the geologically optimized area producing via ground vertical wells. The concluded data will be used as basic data for economic evaluation of target zones of CBM production.
In this report, we predict the production of 6 selected target coal seams where multi-branched horizontal wells are applicable and the purpose of the prediction is compare the different economic benefits between the multi-branch horizontal wells and vertical wells.

1) Basic data

Basic data are necessary to simulate different target areas listed in List 2. To the blocks with incomplete data, we take the coal step as the main standard and adopt analogy method by comparing the adjacent block to access the physical parameters (See Figure 4.18).

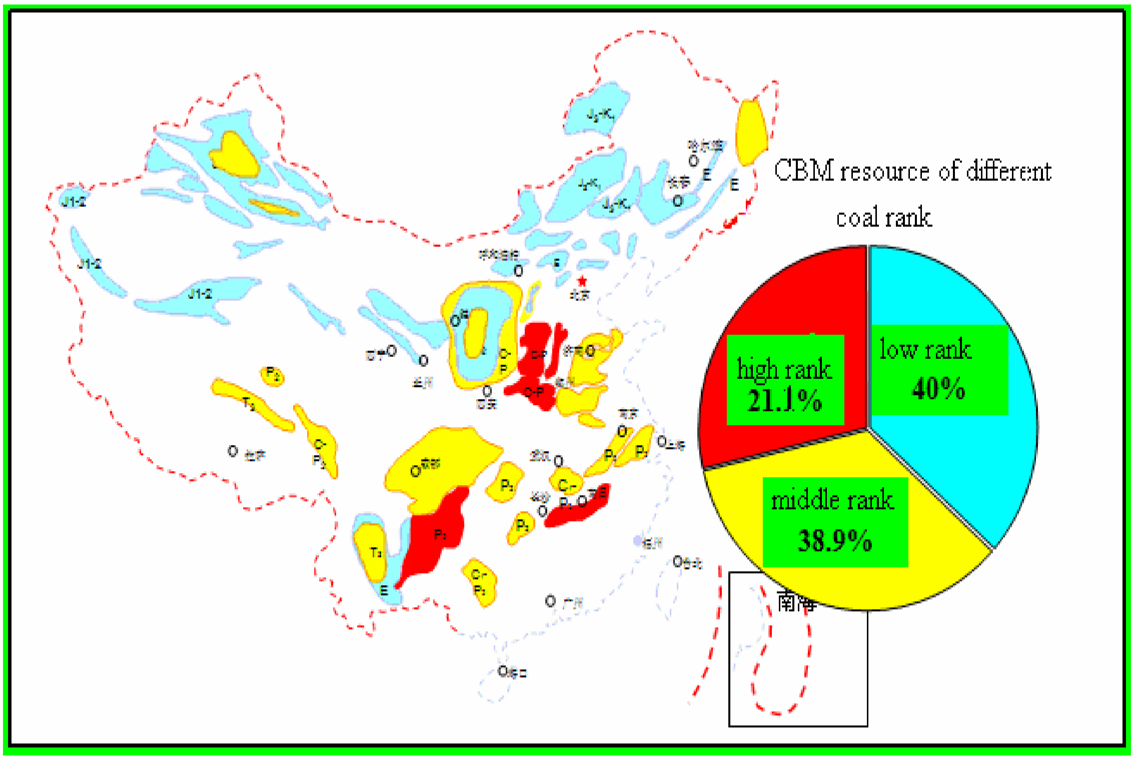

Figure 4.18 Coal rank distribution in China
Source: Zhao Qingbo, Second CBM Symposium of China, 2007.

2) Well network patterns

Reasonable well layout pattern can not only substantially increase the output of CBM wells, but will reduce exploitation costs. CBM well network patterns usually are: irregular patterns, rectangular pattern, five-spot well net etc. Rectangular pattern places wells along the major permeability and in vertical directions, and the four adjacent wells form a rectangular. Rectangular pattern is commonly used in the development of CBM wells for its regularity and convenient arrangement. This simulation uses rectangular pattern as pattern configuration in the development of CBM wells.

3) Well spacing design

There are two main methods to space vertical CBM wells. The first is geological analogy, and the second is numerical reservoir simulation. This study uses numerical simulation, combined with the practical experiences to determine reasonable space between wells. To design 400 m×350 m, 350 m×300 m, 300 m×300 m, 300 m×250 m, 250 m×200 m five well spacing, we use the actual Qinshui Basin reservoir parameters to do the numerical simulation for production prediction to get optimum well spacing. According to the production prediction, with decreased well space, the higher the initial recovery is, the shorter the time to peak is, and the shorter the stable productivity period is, and constant rate period is shorter. When well spacing is increased, the later recovery is higher, constant rate period is longer, and the total production is high. Taking all the factors into account, 350 m×300 m as the optimum well spacing is recommended. The pattern of well location is shown in Figure 4.19.

For multi-branched wells, such model is selected and that is one major branch, eight sub branches. Each side of the major branch has four branches, the angel between branch and major branch is 45°, and the distance between adjacent sub branches is 150m. The length of major branch is 800m, the lengths of sub branches are 500m, 400m, 300m and 200m. The style of the multi-branched well is shown as Figure 4.20.

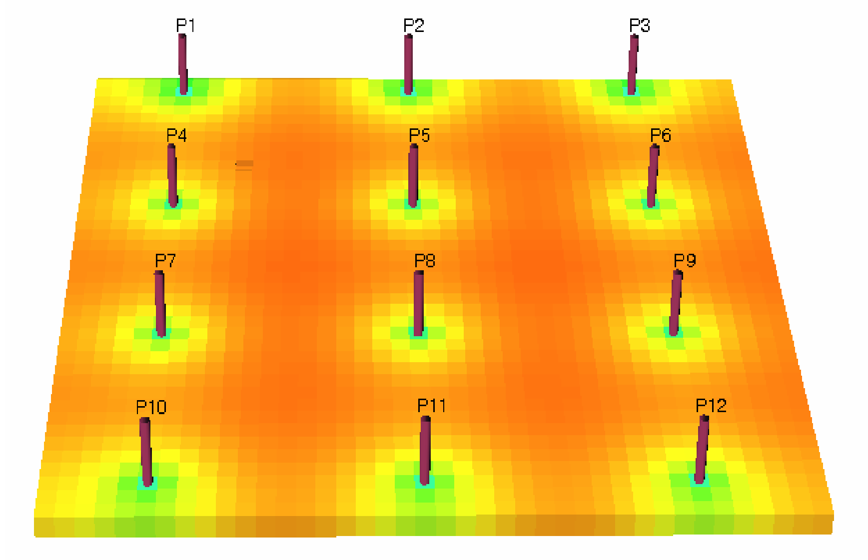

Figure 4.19 Vertical well pattern for production prediction

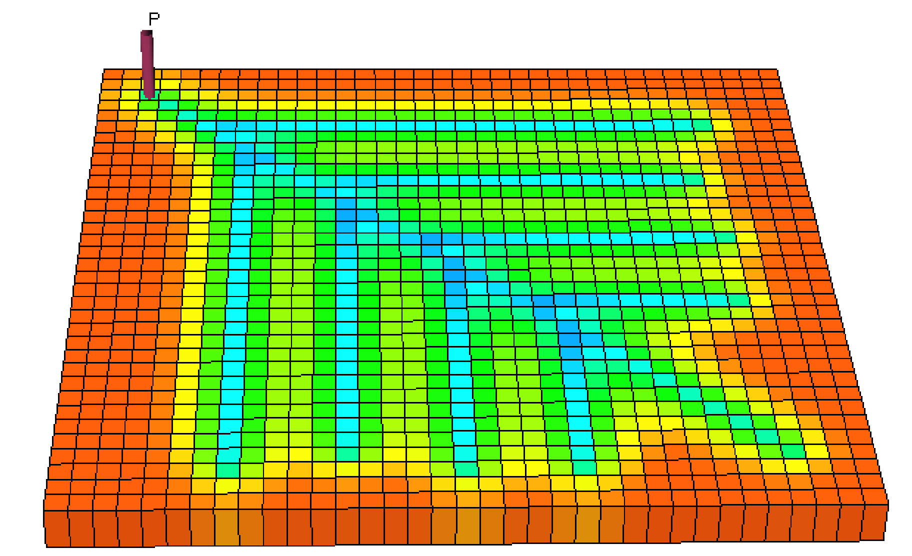

Figure 4.20 Model of multi-branched wells

Production curve of the typical vertical CBM well is as shown in Figure 4.21.

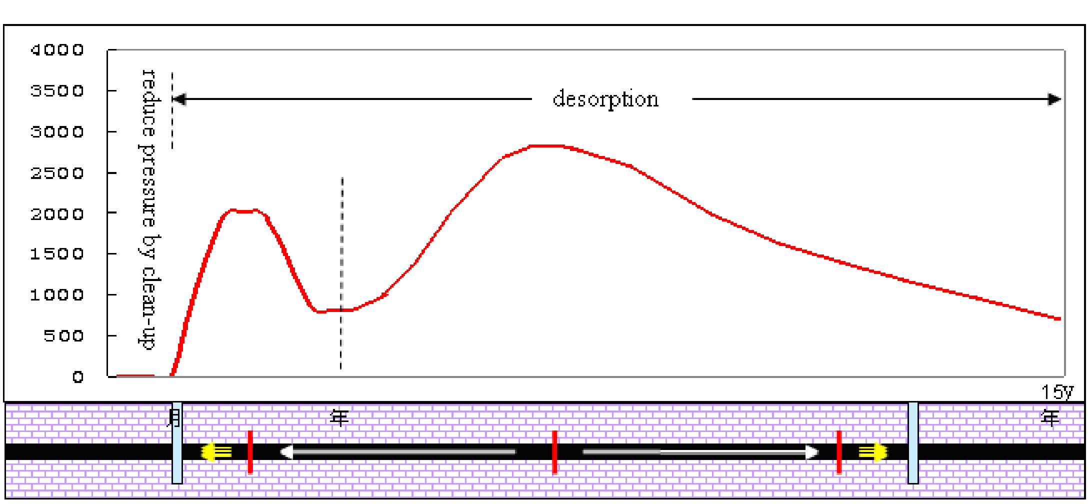

Figure 4.21 Rule curve of the vertical well drainage and extraction

4) The function of CBM production [67]

The function of CBM production：

$Q = f(M_0, A, B, p, h)$

Nomenclature:

Q-total gas production

M_0-gas concentration of original coal

A-CBM pressure coefficient of adsorption

B-Langmuir pressure

p-A given point pressure in the gas production area

h-Thickness of coal

$p = \phi(r_w, r, R')$

Nomenclature：

r_w-Well bore radius；

r-A given point radius in the gas production area；

R'-Characteristic value of pressure curve。

$$R' = \sqrt{\frac{kt}{\phi C_t \mu}}$$

Nomenclature：

k-Permeability of each layer

t-Gas production time

ϕ-Layer porosity

C_t-Liquid compressibility coefficient in the layer

μ-Liquid viscosity。

$R = CR'$ (C is the constant)

Nomenclature：

R-Radius of gas control

Typical production curve of CBM vertical well can be seen as followed:

5) Analysis of production affecting factors

a. The impacts of CBM production on permeability

The permeability of most CBM seams in China is below $1\times10^{-3}\mu m^2$, with limited excaption above $1\times10^{-3}\mu m^2$. Therefore the index number of CBM production is rather small, and production is normally low because of pressure sensitive effects of each layer. So half of the vertical wells need to be fractured, and the typical production from vertical wells can be seen as follows (See Figure 4.22).

b. Effects of adsorption time on CBM production

During CBM production, adsorption time is one of the primary factors determining the desorption speed of the supply source, therefore, and it greatly affects the production. The adsorption time is generally obtained from desorption experiments directly. The adsorption time of Well Jinshi 1 is 1.775 days (42.6h). Figure 4.23 shows the results obtained at different adsorption time but under same conditions. The figure shows the shorter adsorption time is, the quicker diffusion rate is; generally the shorter the time to peak CBM production is, the higher peak production is and the quicker production drops. However, short adsorption time possibly shorten the steady production period of coal bed, and sometimes stable production rate and the gross output of coal beds with short adsorption time may be lower than that of coal beds with long adsorption time. Therefore, adsorption time itself can't accurately evaluate the recovery rate and production rate, and shorter adsorption time is not always more advantageous to CBM production.

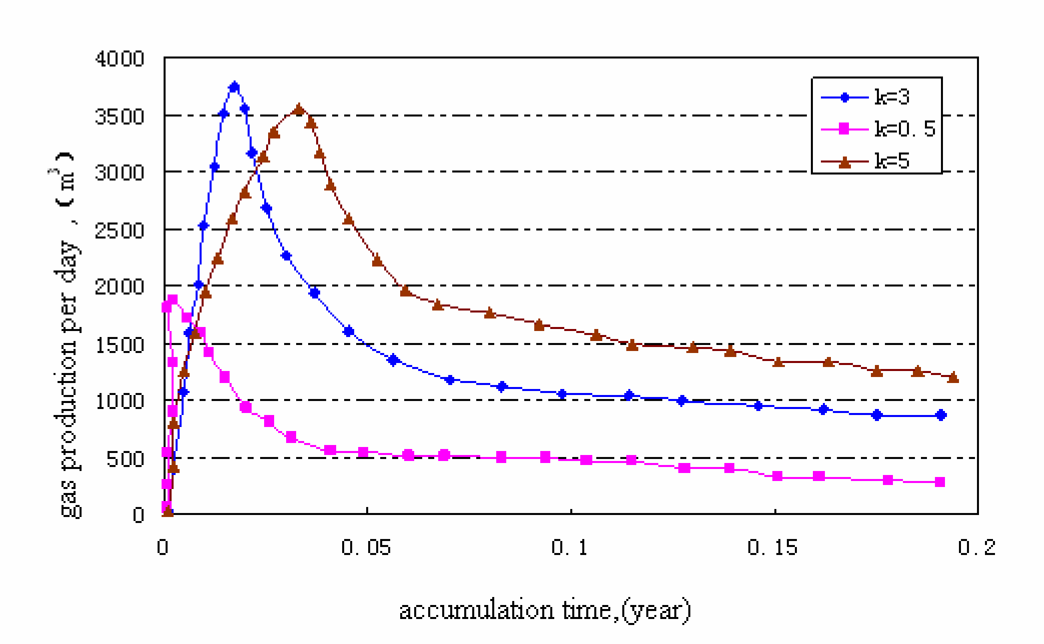

Figure 4.22 The CBM production curve per day at different permeability
Source: Liu Honglin, 2007.

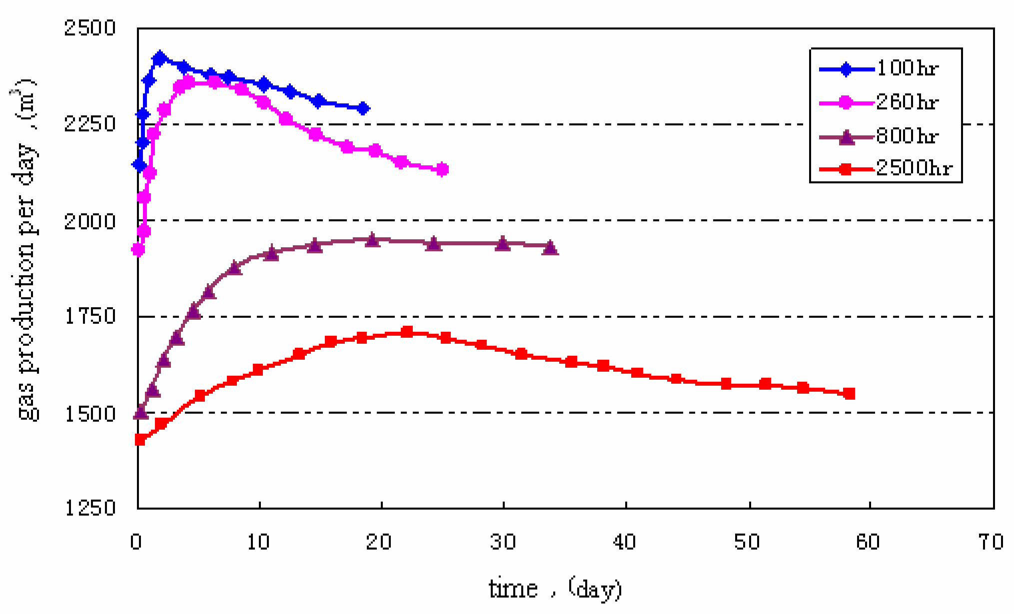

Figure 4.23 Daily CBM production curves of different adsorption time
Source: Liu Honglin, 2007.

c. Effects of adsorption CBM saturation on CBM production

Figure 4.24 shows the production change under different critical desorption pressures, representing ultra saturated, saturated and the undersaturation coal beds, but other parameters are the same. For ultra saturated coal beds, there may be CBM flow and CBM delivering, because free gas occurs when there is some CBM desorbed in any region. It makes CBM output relatively high. For saturated coal beds, the entire mining region will be at desorption condition when production starts. But CBM is not delivered in any place for the reason that saturation of the region far from the borehole is still lower than the residual CBM saturation. The CBM can't flow freely. In undersaturated coal beds, the region under a pressure lower than critical desorption pressure, waste some differentiates pressure energy since there is no gas desorption. Meanwhile, because of the lower CBM content, the peak CBM height would be low and the CBM production afterwards it will drop sharply. The CBM content is lower, and the production is lower.

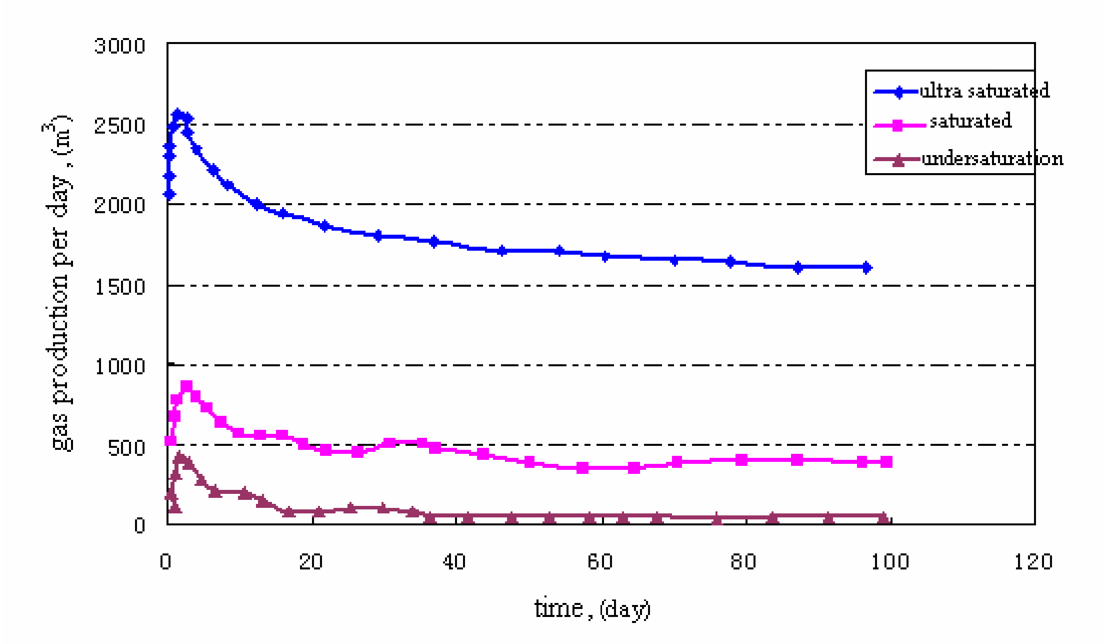

Figure 4.24 Daily CBM production curves of different saturation
Source: Liu Honglin, 2007.

6) Production prediction

Under reasonable production system and with prediction period of 20 years, we use the above-mentioned model to predict production of CBM target areas. The production prediction results of the remaining 61 prospectives are shown in Annexed Table 3 and Annexed Table 4, with 24 definite non-profitable prospectives removed.

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Chapter 5 CBM Economic Evaluation

China has many CBM prospects in its vast territory. In order for the State and related enterprises to make scientific and rational decisions on the investments in CBM industry; we must conduct economic evaluations of the CBM prospects and then give ranking analysis based on the evaluation. Economic evaluations of the favorable CBM prospects selected in terms of the resource evaluation will be undertaken in this chapter on the basis of CBM prospect geological selection and production simulation mentioned in the previous chapters, and then o the basis of the economic evaluation, some recommendations will be given over the decisions about the development of every prospect. In addition, the social benefits from CBM development will be estimated so that we can analyse quantitatively the possible financial subsidies and, accordingly, give suggestions about the further financial subsidies to the marginal CBM prospects.

5.1. Macro Background Analysis of CBM Utilization in China

5.1.1. Stimulation to the CBM Development by the Demand for Natural Gas

The natural gas has attracted more attention and is developed rapidly for its advantages such as sufficient resource, being clean and environmentally friendly, high heat value, high utilization efficiency and low unit heat value price. Since CBM has almost the same physical and chemical characteristics and the same utilization as conventional natural gas, it can be taken as an important supplement to conventional natural gas. According to some predictions, the natural gas demand will be 200×10^9 m^3 in the year 2020 [1]. The main encouraging factors to natural gas demand are development speed of national economy, population growth rate, environmental protection, industry structural adjustment. With the increase of natural gas demand quantity, the demand structure will change also. It means that the proportion used by residents will rise greatly, and the proportions used in power generation and chemical industries will decrease differently.

1) Civil and commercial fuel

Coal and kerosene are the main traditional fuel for cities and cause 90% pollutant and 80% dust pollution in air. The substitution of coal with natural gas can decrease NO_X emission by 80%~90%. CO_2 emission from natural gas burning is 52% lower than that from coal burning, and 26% lower than that from kerosene. Compared with coal and kerosene burning, natural gas burning would decrease the possibility of acid rain and greenhouse effects and, moreover, the air pollution is low because there will be no dust in gas burning. Currently, city fuel is diversified and various fuels are available: coal, kerosene, coal gas, liquid gas and natural gas. Compared with natural gas, the cost of artificial coal gas production is higher and it needs a large amount of government financial subsidy every year. While, liquid petroleum gas is not convenient and not safe in the utilization processes because it is seldom transported through pipeline [2,3]. With the rapid development of Chinese economy, the natural gas demand as residence and commercial fuel is increasing in large scale. On the 30th August 2007, the State Development and Reform Commission issued *Natural Gas Utilization Policy* to encourage the application of natural gas as fuel.

2) Industry and transportation fuels

Industry fields such as construction materials, electro machinery, textile, petrochemical industry and metallurgy can take natural gas as fuel, and they form one of the main natural gas consumption markets. The utilization of gas in various industries can not only increase combustion efficiency, but also can reduce labour intensity and decrease environmental pollution from coal and oil fuels. The pressure from the coal and oil transportation can be relieved [2,3]. As a kind of industrial fuel, natural gas can substitute current coal and fuel oil as common heating fuel and as fuels for some special manufacturing industry or for heating in manufacturing process. *Natural Gas Utilization Policy* permits industries, such as building materials, electro machinery, textile, petrochemical industry and metallurgy, to implement the projects of *substitution of coal with gas* or *substitution oil with gas*.

3) Chemical materials and power generation

Because of the low price of natural gas, natural gas industry has developed rapidly, and the main products are ammonia (urea), methanol (formaldehyde), ethylene (propylene), hydrogen acetylene [2]. Power generation with natural gas is economical and efficient, so, with increasing demand for electric power, the natural gas demand from power generation will be increased. But the *Natural Gas Utilization Policy* stipulated some restriction or prohibition policies in natural gas chemical industry and power industry with power generation with natural gas, so the demand for natural gas in these industries will be strictly controlled.

Based on predictions, the demand for natural gas will keep a rapid increase in the future in China. In the year 2010 the demand for natural gas will reach 100×10^9 m^3, the production will be about 92×10^9 m^3, and the difference between demand and supply is 8×10^9 m^3. In 2020, the demand will increased to 200×10^9 m^3 and about 50% of the demand will depend on imported gas[1,4]. To meet the market demand, China has adopted a strategy: based on domestic natural gas resource, to accelerate the development of domestic conventional gas, and vigorously support the development of CBM. CBM will fully play its complementary and alternative role.

5.1.2. Development of Related Industries and Their Influences on CBM Industry

The main market competitors of CBM, as a kind of un-renewable resource, are coal and natural gas. The formation of any industry and its industrial policy and the supporting laws and regulations will exert complementary or competitive influences on other industries.

5.1.2.1. Development of Coal Industry and Its Influence on the CBM Industry

China is the largest coal production and consumption country in the world. In 2003, the coal production was 1.667×10^9 t, which was 33.5% of total coal output in the world and 74.2% of Chinese primary energy output. Coal plays an important role in Chinese economic and social development. In 2003, 78% of power energy, 60% of chemical materials and 36% of residence and commercial energy were supplied by coal [8]. Since 2003, Chinese coal industry has entered its fastest growing period. In 2007, coal output reached 2.532×10^9 t. In the “11^{th} Five-year Plan” period, the state will adjust the coal industry structure, to integrate, transform and close small coal mines. Meanwhile the government will accelerate the building of large-scale coal production bases, start a set of large-scale modern coal mines and replace lagged production ability. Considering the suspended production capacity of 0.097×10^9 t in 2006~2008, it is forecasted that in 2007~2010, Chinese coal output will be 2.633×10^9 t, 2.925×10^9 t and 3.099×10^9 t respectively, with annual growth of 7.87%, 8.99% and 5.96%. Chinese current coal market, as a whole, is basically balanced in supply and demand. But if the demand becomes stronger, insufficient supply and lack of given type of coal will occur because of lack of potential reserves, limited transportation facilities, and production safety.

The coal industry in China has developed for a long time, and the coal market is mature and has been taking a large share in energy structure and the price of coal is relatively lower. Moreover, the CBM is accumulated in coal seams and the CBM production source must be the main production area of coal too, and this would definitely affect CBM industry and prevent the CBM market from its development. Because of the shortage of energy resource and large market demand, coal will remain a dominant energy in Chinese basic energy consumption in the next 20 years, competition between coal and CBM industry will exist for a long time. The dominant status of coal industry in Chinese energy industry has brought many negative influences such as environment pollution, crop output reduction, forest destruction and strain on road and railway transportation. Compared with coal, CBM is a kind of clean energy with high heat value. The transportation of CBM depends mainly on pipeline. These characteristics bring competitive advantage to CBM in residence and industrial fuel market. With the further recognition to the disadvantageous effects of coal industry, the influence of coal industry to CBM industry will become smaller [3]. Besides, CBM development is important for improving the production safety condition of coal mines. In the process of coal mining, CBM, generally named as “gas” in coal industry, will gradually and continuously swarm from the coal seams into underground mine spaces. The gas in the underground could be concentrated to such content that they could stifle the workers working underground or even result in gas explosion. Coal mine gas accident is one of the most serious threats to coal mine production, and it can be taken as the first of the four most disasters. Reasonable development and utilization of CBM resources through surface extraction, underground extraction, mining area extraction and other methods can not only greatly improve production safety conditions of coal mines, decrease gas-oriented accidents and improve production efficiency, but also can reduce investment and production cost and improve economic benefit of coal mines.

5.1.2.2. Development of Natural Gas Industry and Its Influence on the CBM Industry

In recent years, Chinese natural gas industry has made great progress. The reserves are increased greatly, the annual output rises steadily and more national pipeline network are continuously constructed. Since the beginning of 1990s, China has continuously enhanced natural gas exploration efforts and the natural gas resources have increased rapidly, with $100\times10^9\,m^3$~$400\times10^9\,m^3$ annual new proved geology reserves and $150\times10^9\,m^3$ annual new recoverable reserves. The remaining recoverable reserves are increased from $241.6\times10^9\,m^3$ in 1990 to $26{,}757\times10^9\,m^3$ in 2005, reaching to an R/P ratio of 44 measured by proved reserves. Natural gas output has increased also steadily from $13.5\times10^9\,m^3$ in 1990 to $50\times10^9\,m^3$ in 2005. China has built four main gas production regions: Sichuan, Ordos, Tarim and the sea region. The pipeline transportation capacity has been increased dramatically. National major network has been formed, and a gas transportation model of "transporting west gas to the east"," transporting offshore gas to onshore regions" and "supplying gas to the regions near source" has been primarily put into practice. Gas storage tanks are constructed, and the ability of safe and steady gas supplying is more and more increased. With large scale construction of pipeline network, the gas market is changing ultimately, from merely local consumption to inter-regional consumption. The consumption proportion in the eastern developed coastal regions rises gradually. Eight regional markets have been basically formed: the northeast region, the Bohai Bay region, the Yangtze River Delta region, the southeast coastal region, the central region, the southwest region, the central and western region and the western region [10].

CBM industry is very similar to natural gas industry in resource type and finished products, and thus natural gas industry and CBM industry are natural competitors. According to the analysis of the current development of natural gas industry, CBM industry has met some challenges from natural gas industry to some extent. Firstly, the: "transporting west gas to the east" project makes the natural gas from Xinjiang and foreign countries more favorable in market share in the east. For example, the market of CBM from fields such as Qinshui Basin has been threatened under the current situation. Secondly, compared with natural gas industry, CBM industry has the disadvantages such as lower single-well output, higher production costs, longer investment return period and less economic profits. In contrast, the natural gas development enjoys quicker investment return and more economic benefit, and therefore attracts stronger interest from companies.

Chinese CBM industry has, of course, very strong competing strength. Firstly, CBM is an important substitutor for natural gas，especially in the areas where there is shortage of gas supply. Secondly, CBM has geographic advantages. The Chinese conventional natural gas resources is serious maldistributed, mainly concentrated in 7 basins of Tarim, Ordos, Qaidam, Sichuan, Yinggehai, Qiongdonghai, and Donghai. The regions rich in CBM are in shortage of conventional natural gas and this can create market for CBM.

5.1.2.3. Development of Related Industries and the Influences on the CBM Industry

1) Chemical industry

First, the rapid economy globalization, financial globalization and computerized management provide new development opportunities for petrochemical industry. Second, the everlasting and rapid development of national economy prepared a huge market for petrochemical industry. With the development of market economy, the influence of petrochemical industry on agriculture, auto industry, construction industry and mechanical-electronic industry is even intensified. In the coming 10 years, market demand for domestic petrochemical products will stably increased by 6%~8%, much higher than the world average level. The market demand for chemical products will keep growing. However, the self-sufficient rate of Chinese chemical products is relatively low. The development of national economy requires improved market structure and enhanced technical orientation to meet the great demand for chemical products. On one hand, this would promote the chemical industry to maintain sustainable and stable growth. On the other hand, the raw material demand from chemical industry will increase rapidly. Pure CBM can be used as raw material to produce a series of chemical products, such as formaldehyde, methanol, methylamines, carbamide and carbon black. The usage of formaldehyde is most extensive. It is not only the important raw material for chemical industry, but also cheap auto fuel. Moreover, methanol can be made into methanol batteries and used in other industries. The rapid growth of chemical industry and high oil price will definitely promote the utilization of CBM in the industrial fields.

2) Auto fuel industry

Conventional motor fuel (petrol, diesel) comes mainly from oil. Some new alternative auto fuels used currently or under development are compressed natural gas, liquefied petroleum gas, alcohol (methanol and ethanol), biodiesel, dimethyl ether, gas to liquid, hydrogen used for fuel cells, methanol and clean gasoline. In the future, application of alternative fuels will increasingly expand along with technological progress and increasingly stringent environmental requirement. This is the overall trend of development of motor fuel in the world. The vehicle using natural gas (or CBM) as fuel for substituting gasoline has popularized in many large and medium sized cities. Some coal mines have used the extracted CBM as auto fuel for mine district transportation vehicles instead of oil, and have got considerable economic returns.

5.1.3. Analysis of CBM Utilization Potential

5.1.3.1. Brief Introduction

The progress of CBM (coal gas) utilization in China is not so quick (See Table 5.1). The total domestic CBM consumption is about 1×10^9 m^3 in 2005. The coal gas utilization is mainly concentrated in state-owned key mine with high extraction quantities from underground. The utilization of CBM from ground exploitation is mainly concentrated in the Zaoyuan well groups in Shanxi Qinshui prospect, the Liujia well groups in Liaoning Fuxin prospect, the Panzhuang project in Jincheng prospect, Panhe project in Shanxi Qinnan prospect and so on. The exploited CBM is transported by tank trucks and supplied to the nearby places around the mines. At present, CBM is mainly used as residence and industrial fuels, power generation, auto motor fuels and production of carbon black and so on. Among them, the utilization of CBM for power generation develops quickly, and the total capacity of the installed power generators by burning CBM reached about 200,000 KW at the end of 2005.

According to the"11^{th} Five-year Plan" of Chinese CBM development, the CBM development in these five years will be developed in terms of market demand and by means of technology progress(See Table 5.2, Table 5.3). At the end of 2010, the production capacity will be built to 7×10^9 m^3 and the production rate can reach 5×10^9 m^3. Moreover, the CBM production will exceed 5×10^9 m^3 with an extraction rate of more than 40%, and the amount of gas consumed will add up to 3×10^9 m^3 with a utilization rate of more than 60%.

Table 5.1 Extraction and utilization amount of main coal mines in china (2000~2004)

Year	2000	2001	2002	2003	2004
Extraction amount (10^9m^3)	0.87	0.98	1.15	1.52	1.87
Annual growth rate (%)	10.13	12.64	17.35	32.17	22.76
Utilization amount (10^9m^3)	0.32	0.46	0.46	0.63	0.70
Utilization rate (%)	36.60	46.76	39.62	41.40	37.51

Source: The"11^{th} Five-year Plan" of CBM (gas) development

Table 5.2 CBM surface exploitation amount in the "11^{th} Five-year Plan" (10^9m^3)

Year	2006	2007	2008	2009	2010
Production	0.25	0.90	2.90	3.61	5.02

Source: The"11^{th} Five-year Plan" of CBM (gas) development

Table 5.3 CBM extraction and utilization in in"11^{th} Five-year Plan" (10^9m^3)

Year	2006		2007		2008		2009		2010	
	Extraction	Utilization	E	U	E	U	E	U	E	U
Production	2.616	1.003	3.466	1.759	3.870	2.205	4.582	2.577	5.284	3.201

Source: The"11^{th} Five-year Plan" of CBM (gas) development

5.1.3.2. Potential of CBM Utilization in China

The content of CH_4 in CBM has important influence on the CBM utilization. The CBM with low CH_4 content and middle calorific value is mainly used in residence and commercial sectors, and only a small portion is used in industrial boilers and power generation. The CBM with high CH_4 content and high calorific value can, beside above mentioned applications, also be used in chemical industry, power generation and auto fuels, the process of CBM utilization is similar to that of natural gas. The utilization plan is different in different mine areas, which is determined by the quantity and quality of CBM as well as local energy market. Because of the restriction from the incomplete pipeline network, the nearby utilization of CBM is suitable for China's present situation, because the CBM production regions are generally near to the potential industrial and resident users. The main utilization plans at present are shown in Figure 5.1.

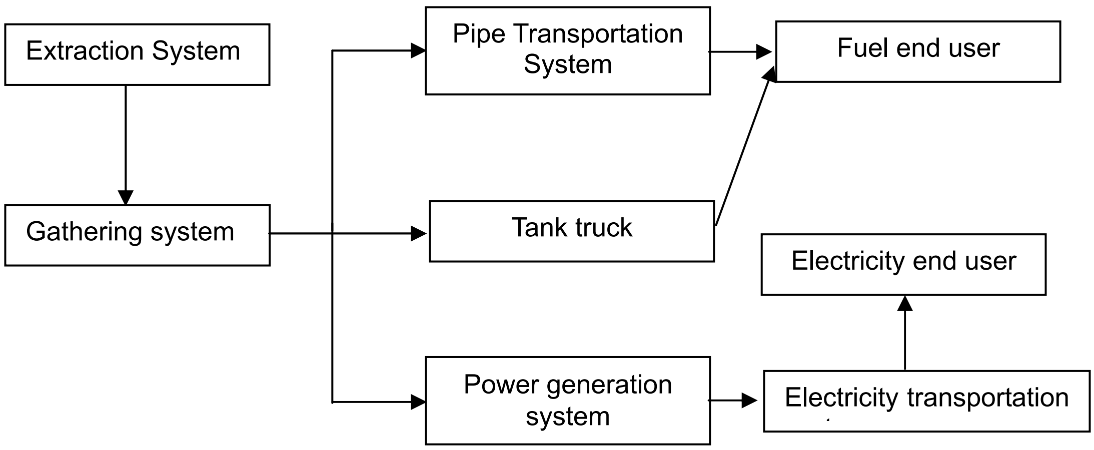

Figure 5.1 Main CBM utilization plans

1) Analysis of the Potential application of CBM to power generation

The market potential of power generation in the CBM source regions is very strong. Large quantity of electricity power is needed for the living and production near the coal and CBM mine areas. The power generated from CBM near the production area can not only satisfy its own demand, but the surplus can also be put into the local electricity network for sale. According to the”11^{th} Five-year Plan” of Chinese CBM development, the predicted extraction of CBM used commonly for power generation will be 5×10^9 m^3 in 2010, and the corresponding utilization quantity will be 3×10^9 m^3. If 1 m^3 CBM can generate 3 KW·h electricity power and the price of electricity is 0.063 USD/KW·h, the total value from the market is predicted to be about 56.96×10^9 USD. Furthermore, it needs less investment for construction of a power plant using CBM than for construction of a power plant using coal, because the expenses for coal treatment, transportation, crushing, smoke prevention, dust control, deslagging can be saved by gas fuel power generation.

2) Analysis of Potential utilization of CBM as residence fuels

The residence utilization should be placed at the first important position, no matter the CBM is from underground extraction or ground exploitation. CBM has many advantages. Its calorific value can be adjusted according to different requirements. It doesn’t contain coal pyrolysate, and cleaning equipment is not necessary. CBM does not jam or corrode transportation equipment. The CBM from underground extraction can be supplied directly to the residents as well as to canteens, hospitals, or schools close to the mine areas. The CBM from ground exploitation can be transported to the near cities through pipelines or immixed into the nature gas pipelines available.

The residence utilization of CBM has following advantages: reducing the resident’s work in using coal, improving living standard, solving the problems of waste residue treatment and smoke and dust pollution caused by coal burning, reducing CO_2 and SO_2 emission and improving the environment of local areas, and reducing the emission of greenhouse gas.

3) Analysis of the Potential utilization of CBM as fertilizer and chemical materials

The chemical utilization of CBM refers mainly to synthesizing CBM into raw material gas through conversion, and then, through other chemical reactions to synthesize material gas into different kinds of chemical products, of which the synthetic ammonia, synthol and hydrocarbon have the best market prospect [2].

a. Synthetic ammonia and the similar products

The process of synthetic gas making through reforming the CH_4 and vapour or partial oxidation can replace the process of making gas from coal in the current synthetic ammonia industry. This can reduce the total investment in factory construction and the environmental pollution from the process of transforming coal into gas and thus result in good environmental, social and economic benefits.

b. Synoil and organic chemical products

The methane can be synthesized into ethylene and ethane through hot polymerization or oxidation dimerization. It can be synthesized into methanol, formaldehyde, dimethyl sulphate, alkylogen and so on through oxidation and it can be also made into synthesis gas through reforming the vapour or partial oxidation. Fuel oil and other chemical products can be synthesized through these three methods together with corresponding chemical reactions.

c. Synthesized methanol and its down-stream products

.Synthesizing of methane into methanol is one of the most mature techniques. The direct and indirect utilization of methanol can be found almost in the whole organic chemical field. Therefore, the synthesizing of the down-stream products with methanol as raw material becomes the effective indirect approaches to methane application.

4) Potential analysis of CBM as industrial and transportation fuel.

The CBM can be used as the fuel of industrial furnace, and it can increase the heat transferring efficiency and improve the productivity. Every coal mine in China is equipped with large or middle sized mechanical repairing plant with all kinds of metal-processing industrial furnaces. Using CBM as fuel instead of coal can improve the combustion efficiency, save energy, and improve product quality, working conditions and economical benefits. With the development of the diversified business in coal industry, the number of silicate furnace increases greatly. Generally, the silicate furnace needs high temperature combustion and it consumes a large quantity of energy. If the CBM is used as the fuel for silicate furnace, the quality of the products can be improved

Vehicle is one of the air pollution sources. It discharges a large amount of carbon monoxide, hydrocarbon and oxynitride. At present, the compressed natural gas and liquefied natural gas are perfect clean fuels of vehicles. Compared with oil fuels, gas can reduce the emission of carbon monoxide and soot and have no emission of harmful materials such as sulphur dioxide, oxynitride, mercury, arsenic, lead etc. CBM and natural gas have the same components and combustion mechanism, so CBM is very suitable for compressed natural gas production and liquefied natural gas as motor fuels.

5.1.4. Prediction of the CBM Market Demand at the CBM Prospects of China

5.1.4.1. The Method for Estimation of the Market Demand at the CBM Prospects

CBM market demand is the base for assessing the scale of initial development and capacity replacement of target areas.Accurate prediction of the market potential of the prospectives is the premise to evaluate the economic conditions of CBM development. As a nationwide pipeline network system is not available in China, the coalbed methane target areas are characterized by lack of natural gas, lack of a nationwide network system, replacement of natural gas with coalbed methane. The market demand prediction in this study takes the surrounding areas and towns of the target areas as the target markets, on the basis of the current natural gas consumption of the provinces that have a basic balance between supply and demand.The prediction offers the present demand with the consideration of the present socio-economic status of target areas. At the same time, the future demand growth will be predicted on the basis of the process of urbanization of the target market .Taking into account the life expectancy of CBM mining system and urban distribution pipeline network facilities, the study sets the period for market prediction and economic evaluation of the target areas as 31 years.

CBM resources can be sold to other further markets in two ways, discovering new markets or replacing the existing natural gas. It is possible to transport CBM to the market far away only when required pipelines are ready. According to the"11th Five-year Plan" of CBM development, the West-East Gas Pipeline and the Shaanxi-Beijing Pipeline provide favorable conditions for transporting CBM. The West-East Gas Pipeline passes through six major CBM-rich prospects--the Xinjiang Tabei Coalfield, the Anhui South Coalfield, the Ordos Basin, the Qinshui Basin, the Henan West Coalfield and the Lianghuai Coalfield. There are pipeline branches at BaJiao in Shanxi Province, at Zhengzhou and at LiangHuai of Anhui Province. The Shaanxi-Beijing pipeline passes through the north part of the Hedong Coalfield in Shanxi Province, and through along the north side of the Qinshui Basin, with pipelines branch at LiuLin. With the establishment of the pipeline string and the rule of the pipeline utilization, some CBM prospect close to these pipelines can utilize them to sale CBM, which will increase the market demand.

5.1.4.2. The Basic Parameters for Estimation of Market Demand at the CBM Prospects

1) Natural gas consumption situation in the province (city) with balance between supply and demand

Beijing, Chongqing City and Sichuan Province are three province and cities with balance between supply and demand, and their natural gas comsumption situations are shown in Table 5.4.

Table 5.4 CBM demand coefficient estimate（2005）

Province (City)	Natural gas comsumption amount（$10^9 m^3$）	Population（10^3）	Comsumption per person（m^3）
Beijing	3.204	12,840	250
Chongqing	3.55	12,640	281
Sichuan	8.952	27,090	330
Average			287

Source：China Energy Statistic Yearbook of 2006;
National Bureau of Statistics of China

2) The urban population at the local and surrounding areas

In this research project, large or middle sized cities with good land transport conditions and of distance to CBM source suitable for tank truck transportation will be selected as the market at the local and surrounding areas of a CBM prospect. The population will be refered to the publishment in the local government website.

3) Urbanization rate

The Urbanization rates of the main Chinese provinces are shown in Table 5.5.

5.1.4.3. Results of the Estimation of the Market Demand of the CBM Prospects

According to the above basic parameters, we can estimate the market demand of the CBM prospects (See Annexed Table 5).

5.2. The Factors Influencing the Economic Characters of CBM Prospects and the Economic Evaluation System

5.2.1. The Factors Influencing the Economic Characters of CBM Prospects

The potential values of CBM resources can only be realized when they are verified and developed in suitable technical and economic conditions. The production of CBM is a complex input/output process, and the technical and economic conditions are the states of various factors influencing the economic characters of this process. The influential factors include: geological factor, economic factor, geographic condition, resources condition and technical progress. Geographic condition, for particular, determines the engineering plan and the selection of equipments, and thus it is of great importance.

Table 5.5 Urbanization rate of provinces and cities (%)

Province (City)	Hebei	Shanxi	Inner Mongolia	Liaoning	Heilongjiang	Anhui
Urbanization Rate	0.68	0.50	0.64	0.45	0.29	0.86
Province (City)	Jiangsu	Henan	Hunan	Hubei	Guangxi	Chongqing
Urbanization Rate	1.69	0.63	0.89	1.11	1.06	0.86
Province (City)	Sichuan	Guizhou	Yunnan	ShaanXi	Gansu	Qinghai
Urbanization Rate	0.86	0.26	0.56	0.65	0.34	0.29

Source: Zhao Qunyi, Zhou Yixing, Wang Maojun, 2005.

5.2.1.1. Geographic Factor

A CBM region with rich resources and possible high productivity is the necessary condition for acquiring ideal production quotas and this condition is determined by the size of coal seam area, coal seam thickness, buried depth, CBM content, gas saturation, permeability, reservoir pressure and critical desorption pressure, etc. These parameters determine the initial geological CBM reserves of CBM of the block, recoverable reserves, investment for capacity construction and the efficiency of resource development of the CBM prospects

1) CBM resource volume

A certain amount of prospect resources and geologic reserves is the necessary basis to obtain benefits from the CBM development. If there is no sufficient geologic reserves, the goal of recycle exploration and exploitation can not be reached and the investment will not have an expected return because the production phase will be too short. In other words, the CBM prospective doesn't have industrial development value. The factors influencing the CBM resource volume include coal-bearing area, coal seam thickness and gas content.

The size of coal-bearing area determines, to some extent, the CBM resource volume. Under the same conditions of other kinds, the larger the coal-bearing area is, the more the resource volume of the prospect is, and the more the CBM resource volume, the longer the production phase will be and larger the development scale will be, and, as a result, the better the economic benefits can be.

A given thickness of the coal seam is the basis for the formation of CBM reservoir. The thicker the coal seam is, the more favorable it is for the reservoir formation. According to the experiences from other countries, the total coal seam thickness per well is more than 10m in the successful commercial CBM production areas. The CBM prospects with only thin coal seams (total thickness < 5m) can not expected to have commercial development value, and in the prospects with coal seams of middle thickness (total thickness is 5-10m) , the stable production period is short, and the development value is not high. The CBM can only be produced separately from each single coal seam by means of fracturing, when the thickness of single coal seam is more than 0.6m.

CBM content is an important index in the economic evaluation of CBM development. Considering the CBM resource conditions in China, coal seams are classified into 3 different types according to their CBM contents: the coal seams poor in CBM (content <4 m^3/t), the coal seams bearing CBM(content: 4 m^3/t~8 m^3/t) and the coal seams rich in CBM (content>8 m^3/t). The coal seams rich in CBM can be further divided into two classes: CBM rich (8 m^3/t~12 m^3/t) and CBM super rich (>12 m^3/t) coal seams [17,19].

2) Physical properties of coal seams

Physical properties of coal seams include permeability, reservoir pressure and critical desorption pressure. Permeability has great impact on the dynamic change of well production and the recovery rate, and it is an important index for economic evaluation of the CBM development. Its influence on the CBM production is mainly expressed in the peak value and peak occurrence time during CBM production. In the reservoirs with higher permeability, the water drainage and pressure release are quicker, the pressured area is larger, the gas desorption is quicker and in large quantity, and, as a result, the CBM production and the recovery are relatively higher. The ratio of critical desorption pressure and reservoir pressure is called critical reservoir pressure ratio, which determines the difficulty in the water drainage and pressure release in the CBM exploitation. Under the condition where CBM content and isothermal adsorb line is confirmed, the larger the critical reservoir pressure ratio is, the easier the desorption will be, and the higher the production is.

3) Buried depth of coal seams

The influence of buried depth to the CBM reservoirs is represented in two aspects: first, the CBM components and the CBM contents are different in zones of different depths in vertical directions.; second, the reaction of coal seams is sensitive to the stress, the pore volume and permeability of coal seams change dramatically along with the increase in the static pressure (the depth) of the overlying strata. With the development of the production technology and economic rationality considered, the maximum buried depth of the CBM reseroirs with exploitation benefits is limited to 1,500 m at present. The increase of buried depth can cause more well drilling investment and more operation costs and, finally, result in negative impacts to the economic results.

4) Tectonic conditions

The tectonic condition (including faults, joints and folds) influences the distribution of wells and the production of gas and water, and it is the key parameter in making the field development plan. Different faults have different production features, and meanwhile, the joints in coal seams can influence the CBM extraction. The joint and cleat systems in the coal seams are of good hydraulic connection and play important roles in the reservoir decompression. The tectonic structure can also affect the costs for drilling fracturing and water treatment and on the drilling success rate. Generally, the successful drilling rate is low and the investment will be increased under the condition of complex tectonic structures, because it is difficult to correctly evaluate the different structures. Although the tectonic structures can create some cleat systems and, thus, increase the permeability, too much underground water can, because of the cleat systems, come into the coal seams and increase the water treatment expenses and can, finally, affect the economical effectiveness of CBM developments. The difference in tectonic types will lead to different investment. In the anticline tectonic structure, no fracturing measures are needed and only litter water can be met and, so, the drilling cost is low. In the syncline tectonic structure, much water can, however, be produced and the investment and costs will be higher [9].

5) Hydrological conditions of coal seams

More attention should be paid to the groundwater in the CBM development, not only because groundwater and CBM are all of liquid category, but also groundwater and CBM can be generated in accompany. CBM formation, transportation, accumulation as well as the resource evaluation, exploitation are all closely linked with groundwater conditions. In the economic evaluation of CBM projects, the influence of groundwater mainly reflects in the changes of the costs of water treatment. When the coal seams contain water, water treatment costs will increase, and then the investment will increase correspondingly. The influence extent of the underground water will, of course, be determined by the water volumes of water-bearing stratums, water quality, and water temperature, its relation with the CBM. In the non-water-bearing stratums which are lack of gravitational water, this relationship is especially obvious. Water increase in the coal seams will cause the decrease of the absorbed methane and, therefore, result in negative impacts to the economical CBM development, because of low gas production rate and more costs for drilling and fracturing [9].

5.2.1.2. Economic Factors

In view of the economy, the factors affecting CBM development include exploration investment, development engineering investment, operating cost, sales revenue, profit and taxes. The exploration engineering investment consists of drilling expenses, well logging, well testing expenses, testing production expenses, comprehensive research and supporting project expenses. The development investment is made up of surface system project investment and drilling projects investment. The sales revenue will be determined by the CBM production, commodity rate and price, and it varies with the stable stage and decrease stage of the resources development.

5.2.1.3. Policy Factors

Different with the natural gas industry, CBM industry met a very good environmental driven condition at its early development stage. Major CBM production countries in the world have all made favorable policies and laws to promote the early development of the CBM industry. The policies that directly affect the economical efficiency of CBM development are from the government subsidies, and the governments have, in turn, also got economic compensation from the more energy security, safer coal mine production and better environmental protection duo to the CBM development. The Chinese government has already made financial subsidy method to subsidize the CBM sales except for the power generation. This must be considered in the economic evaluation.

5.2.1.4. Geographic Factors

As a kind of resource production industry, the economical effectiveness of the CBM industry is restricted by the geographic factors. The geographic locations of CBM resources will greatly affect the exploration and development investment and the exploitation costs and, then , also directly affect the economical profits of the CBM production. The geographic factors affecting the economical development of CBM resources include natural geographical condition, climate condition, geographical location, infrastructure condition, social condition and so on. The effects are reflected in surface system engineering investment, pipeline investment, expense for dealing with the interrelations between industry and agriculture, operating risk and so on.

5.2.1.5. Resources Conditions

In the methane weathering belts and biodegrading belts, the contents of N_2 and CO_2 are usually high; while in the deep coal seams, the content of H_2S is high. All these can easily cause difficulties to the downstream engineering of CBM development, leading to high investment and low benefits. It is, therefore, necessary to take the CBM characters into account in the economic evaluation. The higher the methane content is, the better the resources condition will be.

5.2.1.6. Technology Progress

CBM industry is a technology-intensive industry. In the CBM exploration and exploitation, the technology progress plays a role in increasing operation efficiency, decreasing production costs, increasing exploitation rate, enhancing recovery, changing invalid reserves into recoverable reserves, prolonging the economical service life of CBM resources and so on. Anyhow, the economic reflection of the technology progress is investment decrease and/or benefits increase.

5.2.2. Economic Evaluation System of CBM Prospects

Currently, there are three major CBM development modes: underground extraction, extraction from gob area and surface drilling production. Underground extraction mode serves mainly for the safe production in coal mine. The CBM production is limited and the extraction rate is low. The production of gob extraction is higher, but the production declines quickly, with service life of only 3 to 5 years. The surface drilling production can greatly improve the extraction rate, and the service life of the CBM wells can reach 15 to 20 years. So, the surface drilling extraction is the main method to perform large-scale commercial CBM development in China. The economic evaluation in this research is also under this development mode. A comprehensive description about the calculations of investments, the predictions of costs and sale revenue as well as taxes, and the economic evaluations of the main CBM prospects in China will be given based on the CBM resources evaluation and ranking analysis and CBM production predictions mentioned in the previous chapters. All these calculations, predictions and evaluations are conducted according to the resource conditions of the main favorable CBM prospects and the input-output situations of the CBM projects being carried out now or completed already, and under the guidance of the project economic evaluation methods and the parameter values determining methods in the petroleum industry in China.

5.2.2.1. Basic Methods of Economic Evaluation for CBM Resources

There are many methods for economic evaluations. As one kind of dynamic method, the NPV method can more efficiently reflect the time value of the capitals, but also is a method with more rationality and manoeuvrability. So we will use the NPV method in the economic evaluation CBM prospects in China.

1) The basic formula of NPV method

The basic formula of NPV method is:

$$NPV = \sum_{t=0}^{n}\left(C_I - C_o\right)_t\left(1+i_0\right)^{-t} ,$$

where, the NPV is the economic benefit of the CBM prospect in evaluation period; the C_I is the cash inflow of developing the CBM resources in evaluation period; C_O is the cash outflow of developing the CBM resources in evaluation period; t is the evaluation period, t=1, 2……, 30 year; i_0 is the standard discount rate;$(1+i_0)^{-t}$ is the discount coefficient in t year.

2) Economic evaluation model based on the NPV method

In this study, the economic evaluation of CBM prospectives is based on the yield prediction and market conditions of every CBM target area. The prediscted production capacity of each CBM prospective is baded on an evaluation period of 30 years, and on the capacity-building investment per local unit area, unit cost as well as the fiscal and taxation system and subsidy policy for CBM industry in China. Then based on the factors above, the development benefits of each CBM prospective during the evaluation period is evaluated.

The production capacity of the CBM prospectives is determined by both resource condtions and market conditions. The initial capacity building is primarily determined by the market demand for CBM in the region if the CBM resources are rich. In contrast, the design of initial capacity building should take the stable production as a key factor under the condition that the resources are sufficiently used in the evaluated period. With the extension of recovery time, the production will gradually decline after coalbed methane wells reach peak production. Therefore it is necessary to add new coalbed methane production wells at the appropriate time to offset the reduction of production and ensure the production scale. This is called capacity replacement. When CBM resources are sufficient, the design capacity needs to be adjusted with the market changes, and the adjustment should be reflected in replacement building. That is the design capacity should increase with market growth.

The Cash in-flow and out-flow of the CBM prospect development will be decision before the NPV calculation. The cash in-flow includes sale revenue, circulating fund return, residual value of fixed assets; the cash out-flow includes construction investment, circulating fund, operative cost and tax. Assume t is time variable, the first development area is A_d, the replace areas are A_{c1} 、 A_{c2} ……, the CBM production per unit area is $q(t)$, total productions are $q_d(t) = q(t)\times A_d$, $q_{c1}(t) = q(t)\times A_{c1}$, $q_{c2}(t) = q(t)\times A_{c2}$ ……, the construction investments are $I_d(t)$, $I_{c1}(t)$, $I_{c2}(t)$……, annual production in the evaluation period is $Q(t) = q_d(t) + q_{c1}(t) + q_{c2}(t) +$……, the first station price is p_w, the commodity rate is f_s, the circulating fund is C_l, the average unit operative cost is c_j, the operative cost is $C_j(t) = Q(t)\times c_j$, the tax is $T_x(t)$, the basic discount rate is i_0.

$$NPV= \sum_{t=2}^{31}Q(t)\times P_w \times f_s \times(1+i_0)^{-t} + C_l(1+i_0)^{-31} -$$

$$\sum_{t=\text{产能建设时间}}(I_d(t) + I_{c1}(t) + I_{c2}(t))\times(1+i_0)^{-t} -$$

$$\sum_{t=2}^{31}C_j(t)(1+i_0)^{-t} - C_l(1+i_0)^{-1} - \sum_{t=2}^{31}(T_x)_t(1+i_0)^{-t}$$

5.2.2.2. Parameters Estimation for Economic Evaluation of CBM Prospects

The parameters estimation for the economic evaluation of the CBM prospects includes the direct expenditure estimation and the direct benefit estimation. The direct expenditures are the investment, the production cost, fees, the taxes and the investment in the production period. The direct benefits are the revenues from the CBM sales.

1) Investment

The investment of the CBM development includes the CBM development construction investment, the loan interest in construction period, liquid capital and the fixed investment direction adjustment tax.

The CBM development construction investment consists of the fixed assets investment, the intangible assets investment, the deferred assets and the provision expense. The fixed investment can be divided into the drilling engineering expense, the surface engineering expense and other fixed expense.

2) Production cost and expenses

The production cost of the CBM development is the expenditure used in the CBM production, including operation cost and the depreciation and depletion. The operation cost includes the material, fuel, power and staff costs needed in the CBM production.

Other expenses include administrative expense, financial expense and marketing expense, respectively applied in the administration, production organization, financing and product marketing. The administrative expense consists of the amortization expense of the intangible assets and the deferred assets, the mineral resources compensation fee and other administrative expense. The financial expense is mainly the interest expense, in addition, also including the exchange loss, the commission charge, etc.

3) Tax

According to the Chinese Tax Law and preferential policies for the CBM industry, the taxes paid for the CBM development are the city maintenance construction tax, the extra charges of education funds, the income tax and other local taxes.

4) Income

The income from the CBM commodity sale includes the sale revenue and the subsidy revenue. The sale revenue is an income from the CBM commodity sale, and the corresponding parameters include the annual CBM production, the CBM commodity rate and the CBM price. The subsidy revenue is an income from the Chinese government for the sale of the CBM commodity to the users except for the electricity generation users, and the corresponding parameters include the annual CBM production, the CBM commodity rate and the CBM subsidy rate.

5.2.2.3. Methods for Estimation of the Parameters of CBM Prospects

1) Investment estimation

According to the *Economic Evaluation Methods and Parameters for the Construction Projects in PetroChina Co. Ltd.*, the main formulas for calculation of the investment for CBM development in China are as follows:

Investment of the CBM development = construction investment + the loan interest in construction period + the liquid fund + the fixed investment direction adjustment tax

Construction investment = the fixed investment + the intangible investment + the deferred assets + the provision expense

Fixed investment = the engineering expense + other fixed expense

Engineering expense = the drilling engineering expense + the surface engineering expense

a. Drilling engineering investment

Chinese CBM development has two major drilling plans: one is the vertical surface drilling plan; the other is the multi-lateral horizontal well plan. Currently, the vertical surface drilling technology is more mature with less risk and frequent application. The multi-lateral horizontal well technology is still at a pilot stage with more risk and less application, but it is suitable for the Chinese CBM reservoirs with low permeability and may be widely used in the future. Therefore, we take the vertical ground drilling investment and the multi-lateral horizontal well drilling investment into account in the evaluation. According to the different purposes, the CBM wells can be classified into the parameter well, the pilot well and the production well, and the investments for each type are also different. But the accuracy requirement in the CBM resources evaluation can be satisfied even though we do not consider the differences between wells of different types. In the drilling investment estimation in this research, the well types are taken into account. In addition, some investments change significantly with the well depth, and other investments have almost no change during the current well depth range, so the drilling investment can be divided into the fixed expense and the variable expense. Among them, the fixed expenses of the vertical ground drilling include the engineering investment before drilling, the logging engineering investment, the fracturing engineering investment and the drainage and extraction equipment investment. The variable expenses mainly refer to drilling expenditures. The fixed expenses of the multi-lateral horizontal well drilling engineering include the engineering investment before drilling, the engineering well investment, the logging engineering investment and the drainage and extraction equipment investment. The variable expenses mainly refer to drilling expenditures. Accordingly, the CBM development drilling investment can be estimated in accordance with the following formula:

$$C_z = (h_1 \times c_{1v} + c_{1f}) \times \omega_1 + (h_2 \times c_{2v} + c_{2f}) \times \omega_2 \quad (1)$$

In the formula (1), C_z refers to total investment in drilling engineering of CBM development, USD; h_1 refers to the average depth of the vertical ground wells, m; c_{1v} refers to the unit comprehensive variable cost of the vertical ground wells, USD/m; c_{1f} refers to the comprehensive fixed cost of the vertical ground wells, USD; ω_1 refers to total number of the vertical ground wells; h_2 refers to the average depth of the multi-lateral horizontal wells, m; c_{2v} refers to the unit comprehensive variable cost of the multi-lateral horizontal wells, USD/m; c_{2f} refers to the comprehensive fixed cost of the multi-lateral horizontal wells USD; ω_2 refers to total number of the multi-lateral horizontal wells.

b. Investment in surface construction engineering

The surface construction engineering investment consists of expenses in surface engineering design, the monitoring centre, the gas pipeline network, the gas gathering station, the gas compression station, the gas gathering pipeline network, the power supply system, the water supply system, the automatic control system, the terminal station, etc. The surface engineering design and the monitoring centre have no obvious relationship with the number of CBM wells, but linear relations can be established between the other expenses and the number of wells. According to a surface construction engineering design plan of a CBM development project, every 10 vertical wells can converge into one gas gathering station, and every 6 gas gathering stations and 2 multi-lateral horizontal wells can converge into 1 gas compression station, and finally all of them can converge into the terminal station. According to the practical experiences of the CBM production, the production rate of multi-lateral horizontal well is 10 to 15 times of the production rate of a vertical well. Here we use the ratio of “10 times”, and, therefore, each gas compression station can deal with so much CBM as the total production of 80 vertical wells from 8 gas gathering stations. Accordingly, the surface construction engineering investment for the CBM development can be estimated with the following formula:

$$C_d = S_1 + S_2 + S_3 + S_4 + S_5 + S_6 + S_7 + S_8 \quad (2)$$

$$= S_1 + s_2 \times n_2 + s_3 \times n_3 + s_4 \times n_4 + s_5 \times n_5 + s_6 \times n_6 + s_7 \times n_7 + (s_{81} \times n_{81} + s_{82} \times n_{82}) \quad (3)$$

Where, $n_2 = \omega_1/10$; $n_3 = (\omega_1+10\omega_2)/80$; $n_4 = n_{3;}$ $n_5 = n_{3;}$ $n_6 = n_2$; $n_7 = n_3 + 1$; $n_{81}=\omega_1 + \omega_2$, $n_{81}= n_3 + 1$.

In the formula (2), C_d refers to the total investment in surface construction engineering, USD; S_1 refers to total investment in the surface engineering design and the scheduling control center, USD; S_2 refers to total investment in the gas gathering station, USD; S_3 refers to total investment in the gas compression station, USD; S_4 refers to total investment in the terminal station, USD; S_5 refers to total investment in the gas pipeline network, USD; S_6 refers to the investment in gas gathering pipeline network, USD; S_7 refers to total investment in the automatic control system, USD; S_8 refers to total investment in the power engineering and water supply engineering, USD.

In the formula (3), s_2 refers to the quota of investment in 1gas gathering station, USD; n_2 refers to the number of the gas gathering stations; s_3 refers to the quota of investment in 1 gas compression station, USD; n_3 refers to the number of the gas compression stations; s_4 refers to the quota of investment in all the terminal stations matching to 1 gas compression station, USD; n_4 refers to the number of the matched gas compression stations; s_5 refers to the quota of investment in the gas pipeline network matching 1 gas compression station, USD; n_5 refers to the number of the matched gas compression stations; s_6 refers to the quota investment in the gas gathering network matching 1 gas gathering station, USD; n_6 refers to the number of the matched gas gathering station; s_7 refers to the quota of investment in the automatic control system matching 1 gas compression station (or 1 terminal station), USD; n_7 refers to the number of the matched gas compression stations and terminal stations s_{81} refers to the quota of investment in the power and water supply engineering matching 1 vertical well (or 1 multi-lateral horizontal well), USD; n_{81} refers to total number of the vertical wells and the multi-lateral horizontal wells; s_{82} refers to the quota of investment in the power and water supply engineering matching 1 gas compression station (or terminal station), USD; n_{82} refers to total number of the matched gas compression station and terminal station.

c. Other expenses of the fixed assets

Other expenses of the fixed assets of the CBM development are the land acquisition compensation fee. It can be estimated according to the following formula:

$$C_o = C_V \times \omega_1 + C_H \times \omega_2 \quad (4)$$

d. Intangible assets

According to the economic evaluation of the CBM development projects, the intangible assets will not be taken into calculation in general.

e. Deferred assets

The deferred assets of a CBM development project are mainly the production preparation expense and the office furniture purchase expense. There are two methods to estimate the deferred assets: one is to estimate the deferred assets according to the practical deferred assets in the pilot test regions and referring to the price level of the regions where the CBM project to be evaluated is located. The other is to estimate the deferred assets in accordance with the following formula:

$$C_d = I_f \times r_d \quad (5)$$

In the formula (5), C_d refers to the deferred assets; I_f refers to the fixed assets; r_d refers to the deferred assets rate.

f. Provision expenses

The provision expenses include the basic provision expense and the price difference provision expense. Generally, the price difference provision expense needn't to calculate. The basic provision expense can be estimated according to the following formula:

$$C_y = (I_f + I_d) \times r_y \quad (6)$$

In the formula (6), C_y refers to the basic provision expense; I_f refers to the fixed assets investment; I_d refers to the deferred assets; r_y refers to the basic provision expense rate.

g. Fixed assets investment direction adjustment tax and loan interest in the construction period

Currently, the fixed assets investment direction adjustment tax has been suspended. The loan isn't considered in this research, so the loan interest in the construction period will not taken into account.

h. Liquid capital

At the stage of the CBM development feasibility study, the liquid capital can be estimated by using the method of expanding index estimation, and the formulas are as follows:

$$C_l = C_j \times r_l \quad (7)$$

$$\text{or } C_l = R_s \times r_l \quad (8)$$

In the formula (7), C_l refers to the liquid capital, USD; C_j refers to the average annual operating cost, USD; r_l refers to the proportion of the liquid capital to the average annual operating cost.

In the formula (8), C_l refers to the liquid capital, USD; R_s refers to the sale revenue, USD; r_l refers to the proportion of the liquid capital to the sale revenue.

2) Cost and expense estimation

The CBM production cost and expense consist of four parts: the CBM production cost, the administrative expense, the financial expense and the marketing expense. An the stage of the CBM development feasibility study, the CBM operating expense, other administrative expense, the financial expense and the marketing expense can be estimated in accordance with the comprehensive quota of the unit production cost. In this feasibility study, the financial expense isn't considered, so the above comprehensive cost equals to operating cost in the CBM development. In addition, the intangible assets aren't taken into consideration, either. Therefore, the CBM operating cost and expense can be estimated according to the following formula:

CBM operating cost and expense = Operating cost and expense of the CBM development + Depreciation + Depletion + Amortization of deferred assets

a. Operating cost and expense of the CBM development

The operating cost and expense of the CBM development can be estimated by using the following formula:

$$C_j(t) = c_j \times q(t) \tag{9}$$

In the formula (9), $C_j(t)$ refers to the operating cost and expense in year t in the CBM production period, USD; c_j refers to the quota of operating cost and expense of the unit CBM production, USD/m^3; q(t) refers to the production in year t in the CBM production period, m^3/year;

b. Depreciation

According to the *Notice on the Taxation Policy Problems Concerned to Accelerate the CBM Extraction* issued by the Ministry of Finance and the State Administration of Taxation, the accelerated depreciation method can be applied in the economic evaluation of CBM extraction projects. The depreciation method can be the double-residual declining method or the sum-of-years-digits method. In this feasibility study, the sum-of-years-digits depreciation method will be adopted. Generally, this depreciation method can be described as follows:

Annual rate of depreciation = (1- Expected residual value rate) × Annual depreciation factor

Annual depreciation factor = $t / \sum_{t=1}^{N_1+N_2} t$ **, t=1, 2… N_1+N_2**

Annual depreciation amount = Fixed assets × Annual rate of depreciation

According to the characteristics of the CBM production, the cost concerning dismantlement, restoration and abandoned wells should be considered in depreciation calculation. In order to simplify the calculation, the expected net residual value rate is set to be 0 in this feasibility study, and, therefore, the annual amount of depreciation can be calculated as follows:

$$C_D(t) = I_f \times \left(t / \sum_{t=1}^{N_1+N_2} t \right), \ i=1,2,\ldots\ldots,N_1+N_2 \tag{10}$$

In the formula (10), $C_D(t)$ refers to the depreciation amount of year t. USD; I_f refers to total fixed assets investment, USD; N_1 refers to the years of stable production, year; N_2 refers to the years of decreasing production, year.

c. Amortization of deferred assets

From the beginning of the CBM production, the deferred assets will be amortized equally in five years.

3) Tax estimation

a. Value added tax (VAT)

According to the *Notice on the Taxation Policy Problems Concerned to Accelerate the CBM Extraction* issued by the Ministry of Finance and the State Administration of Taxation, the method of *drawback after levy* can be adopted in dealing with the VAT in the evaluation of the CBM development projects, so VAT doesn't affect the economic effects of a CBM project. But as a foundation to calculate other taxes, it is still necessary to calculate the VAT in CBM development. VAT will be estimated according to the proportion of the sale revenue. This proportion will be fixed on the basis of the current tax level of the CBM pilot test regions. The estimation formula is as follows:

$$T_v(t) = R_s(t) \times r_v \qquad (11)$$

In the formula (11), $T_v(t)$ refers to the VAT payable, USD; $R_s(t)$ refers to the sale revenue in year t, USD; r_v refers to the proportion of the VAT to the sale revenue.

b. City maintenance and construction tax, Extra charge of education funds and other local taxes

All of these taxes and charges are calculated based on the VAT payable, and their total amount can be estimated in accordance with the following formula:

$$T_c(t) = T_v(t) \times r_c \qquad (12)$$

In the formula (12), $T_c(t)$ refers to total amount of the city maintenance and construction tax, the extra charge of education funds and other local taxes in year t, USD; $T_v(t)$ refers to the VAT payable in year t, USD; r_c refers to the fee rate of these taxes and charges.

c. Income tax

The formula to calculate the income tax is as follows:

$$T_i(t) = I_T(t) \times r_i \qquad (13)$$

In the formula (13), $T_i(t)$ refers to the income tax payable in year t, USD; $I_T(t)$ refers to the taxable income in year t, USD; r_i refers to the income tax rate.

4) Revenue estimation

a. Sale revenue

The CBM sale revenue can be calculated in accordance with the following formula:

$$Rs(t) = q(t) \times fs \times p_w \qquad (14)$$

In the formula (14), Rs(t) refers to the CBM sale revenue in year t, USD; q(t)refers to the CBM production in year t, m^3; fs refers to the CBM commodity rate; p_w refers to the CBM price.

b. Subsidy revenue

The CBM subsidy revenue can be calculated with the following formula:

$$R_b(t) = q(t) \times fs \times r_b \qquad (15)$$

In the formula (15), $R_b(t)$ refers to the CBM subsidy revenue in year t, USD; q(t) refers to the CBM production in year t, m^3; fs refers to the CBM commodity rate; r_b refers to the CBM subsidy rate.

5.2.2.3. Basic Data for Economic Evaluations of CBM Prospects

1) Basic data of the CBM development in Qinshui Basin

The CBM exploration and development activities are mainly concentrated in the Qinshui Basin, so we can take the data of CBM development in Qinshui Basin as basic data for the feasibility study. Based on the analysis of the economic parameters from some pilot test regions in the Qinshui Basin and on the analysis of the differences in investment and cost of different enterprises, the basic data of the CBM development in the Qinshui Basin have been obtained, and shown in Table 5.6.

2) Analogy method for analysis of the basic data in other CBM prospects

The geographical location, surface conditions, climate conditions, infrastructure conditions and social conditions of the region where CBM prospects are located have great influences on the surface construction investment and operation cost. We can, therefore, estimate the surface construction investment and operation cost with the analogy method. The analogy coefficient can be estimated according to the statistical data of the surface construction investment and operation cost of the petroleum fields near to the CBM prospect, as shown in Table 5.7.

Table 5.6 Basic data of CBM development in Qinshui Basin

No.	Parameters	
1	**Investment parameters**	
1.1	**Vertical well**	
1.1.1	Variable expense per well	620,25 USD/well (450m), ±101 USD/±1m
1.1.2	Fixed expense per well	110,278 USD/well
1.2	**Multi-lateral horizontal well**	
1.2.1	Variable expense per well	100,784USD/well(500m), ±101 USD/±1m
1.2.2	Fixed expense per well	2,162,303 USD/well
1.3	**Surface engineering**	
1.3.1	Fixed expense	1,898,734 USD
1.3.2	Plan 1*: Unit expense of new construction	355,063 USD/ km^2
1.3.3	Plan 1: Unit expense of succeeding	663,29 USD/ km^2
1.3.4	Plan 2**: Unit expense of new construction	390,000 USD/km^2
1.3.5	Plan 2: Unit expense of succeeding	53,569 USD/km^2
1.4	**Other assets**	2% of fixed assets investment (excluding land occupation charge)
1.5	**Basic provision expenses**	2% of fixed assets investment
1.6	**Circulating funds**	2% of fixed assets investment
2	**Cost and expenses parameters**	
2.1	**Depreciation**	sum-of-years-digits depreciation method
2.2	**Operating cost**	0.040506 USD/m^3
3	**Revenue parameters**	
3.1	**Station price**	0.12658 USD/m^3 (including VAT)
3.2	**Government subsidy**	0.025316 USD/m^3 (not for electricity generation)
3.3	**Commodity rate**	95%
4	**Tax parameters**	
4.1	**City maintenance construction tax**	10% of VAT payable
4.2	**Extra charge of education funds**	
4.3	**Other local taxes**	
4.4	**Income tax**	25%
5	Construction and production period	1 year; 30 years
6	Basic earning rate	8%; 10%; 12%

Note: *Plan 1 refers to all vertical wells, with controlled area per well of 0.1 km^2 and minimum construction area of 0.1 km^2;

**Plan 2 refers to 20% multi-lateral horizontal wells, with controlled area per well of 0.5 km^2 and minimum construction area of 2.5 km^2.

Table 5.7 Analogy coefficients of development data of the CBM belts in China

Surface Investment	Operation cost	CBM Belts
1	0.90	Chuandong, Chuannan
1	1.00	Qinshui, Huoxi, Datong-Ningwu, Lianghuai
1	1.10	North edge of Huabei, Jingtang, Jizhong, Xiangzhong-Ganzhong
1.3	1.10	Hunjiang-Liaoyang, Liaoxi
1.4	1.10	Sanjiang-Mulinhe
1.9	1.10	Huainan
2.4	1.10	Hailaer
2.8	1.10	Erlian Basin, Taihangshan Donglu
3.6	1.20	East edge of Ordos Basin, Ordos, Weibei, Zhuohe
3.8	1.20	Qianbei, Diandong-Zhina, Qiangui
3.9	1.20	Tuha

5.3. Economic Evaluations of the Main CBM Prospects

The economic evaluation of CBM prospects will be conducted in the orders of the ranking resulted from CBM resource evaluations. Based on the production prediction and parameters estimation of CBM prospects, the NPV method will be used to calculate the economic effectiveness of the prospects and to do the sensitivity analysis.

5.3.1. Economic Comparison between Vertical Well and Multi-Lateral Horizontal Well

Using multi-lateral horizontal well to develop CBM resources is still at test stage of small scale and there are little experiences to learn from, and therefore the economic evaluations with comparison of the two different well types will be carried out only to the CBM prospects with good geological conditions. The results are as shown in Table 5.8.

Table 5.8 Results of the economic evaluations with comparison of different well types

Prospects	NPV (10^3 USD)		ΔNPV
	Two well types plan	Pure vertical well plan	
Hancheng	37,590.7	57,757.11	-20166.4
Ningwu	167,482.9	176,676.6	-9193.67
Jincheng	312,564	329,520.5	-16956.6
Jiyu	179,014.9	207,050.7	-28035.8
Dacheng	214,133.1	246,071.1	-31938.1

Note: Two well types plan means that theratio of the cotrolling area of vertical well and that of multi-lateral well is 4:1

In the practice of American CBM development, the successful application of horizontal well has resulted in much increase in the CBM production, and this promoted the rapid development of CBM industry in USA. The coal reservoirs in China are mostly of low pressure, low permeability and low saturation, which lead to the low economic benefits from CBM projects with vertical well exploration, and restrict the development of CBM industry of China. From the comparison results above, however, we can see that the economic benefit of CBM exploration under the multi-lateral horizontal well plan performs o better than mere vertical well plan, so the multi-lateral horizontal well plan is hard to spread. The reasons are that the localization of equipment and the key technology is insufficient , and it needs to use the foreign advanced instrument ,equipment and personnel service .These cause the high cost of drilling project and influence the development benefit of multi-lateral horizontal well.

5.3.2. Economic Evaluation of Typical CBM Prospect

Hancheng prospect is one of the active areas of CBM activities, and we will take Hancheng prospect as an example to demonstrate the economic evaluation process. The economic evaluation process includes sequent basic data analysis, production prediction, market demand prediction, concept development programmer designing, parameter estimation, economic indexes calculating.

1) Basic data analysis

According to the collected exploration data, the total CBM bearing area in Hancheng prospect is 4,309.85 km^2, the burying depth is 300 m~900 m, and other geological parameters are shown in Annexed Table 2.

2) Production prediction

Based on the geological parameters of the Hancheng prospect, some simulation calculations have been done with help of the software and the daily production rates over 20 years have been obtained, the specific data of which are shown in Annexed Table 3. Through analysis of the production and referring to the development experiences of the CBM development in Qinshui Basin, the well life is determined to 15 years.

3) Market demand prediction

The market of Hancheng CBM prospect includes the nearby cities such as Hancheng, Xi'an, Qinnan. The current market capacity is about 1.73×10^9 m^3.

4) Concept development program design

The resources of Hancheng prospect are sufficient to meet the total market demand. So we determine the first production capacity to be 1.73×10^9 $m^3\times10^9$ m^3 , the work time of CBM wells to be 330 days per year, and the designed stable production per well to be 6.7×10^6 m^3 and, consequently the first construction area to be 254 km^2.

Because there are sufficient CBM resources in the prospect, the designed production capacity in succeeding periods should increase with the change of the market demand. Hancheng prospect is located in Shaanxi Province, and the urban population growth rate is 0.65%. The succeeding time are set to be in year 5, 8, 11, 15, 19 and 21 separately, and the corresponding market capacities are estimated to 1.79×10^9 m^3, 1.82×10^9 m^3, 1.86×10^9 m^3, 1.91×10^9 m^3, 1.96×10^9 m^3 and 1.98×10^9 m^3.The new designed production are also determined accordingly, and, thus, the exploitation area are set to be 74 km^2, 55 km^2, 54 km^2, 162 km^2, 68 km^2 and 74 km^2 separately in succeeding times. Based on the exploitation areas and productions of the past years, we can obtain the total production of every year in the evaluation period, as shown in Annexed Table 6.

5) Parameters estimation

According to the analogy coefficients of Hancheng prospect, the unit surface construction investment is 1,278,227 USD/km^2, and the operation cost is 0.0486 USD/m^3 in the CBM production. The surface equipments matched to the originally designed production capacity can still be used when succeeding; the unit surface construction investment is 238,784 USD /km^2, when the former surface equipment is fully used. The designed well depth is 908 m in this prospect, and the investment is 218,721 USD per well. According to the designed concept development program, we can calculate the annual total investment in the evaluation period, as shown in Annexed Table 6.

6) Economic indexes calculation

By inputting the production, the total investment, the operation cost of every year during the evaluation period into the economic evaluation software, we can obtain the economic evaluation results of the Hancheng prospect. The NPV is $391,614.57\times10^3$ USD when the basic discount rate is 8%, and the NPV will be 202,433.84×10^3 USD when the basic discount rate is 10%, while, the NPV will be 57,757.11×10^3 USD, when the basic discount rate is 12%.

The sensitivity analysis over the parameters of price, production and operation cost was made based on the basic discount rate of 12%, with results in Table 5.9. The analysis shows that the CBM price is the most sensitive factor and can cause the most influence on the NPV; the following data are the CBM production and the operating cost.

Table 5.9 Sensitivity analysis of Hancheng prospect (10^3 USD)

Change rates	-20%	-10%	0	10%	20%
NPV(Price)	-273,489.44	-103,723.86	57,757.11	219,237.91	380,718.73
NPV(Production)	-158,921.38	-49,244.71	57,757.11	164,758.95	271,760.82
NPV(Operation cost)	166,715.08	112,236.10	57,757.11	3,278.13	-51,200.86

5.3.3. Economic Evaluation Results of Other CBM Prospects

The vertical well production, market, investment and cost of each CBM prospect are shown in Annexed Table. By means of the same economic evaluation process as in Hancheng CBM prospect, the economic evaluation results of 30 main CBM prospects in China are shown as follows, and results of the other CBM prospects are shown in annex 2.

1) Xuanxia

Through the economic evaluation of Xuanxia prospect, we got the result that the financial NPV is 248,338.83×10^3 USD when the basic discount rate is 8%, and the NPV will be 179,332.93×10^3 USD when the basic discount rate is 10%, while, the NPV will be 126,482.34×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done on the basis of the basic discount rate of 12%, with results in Table 5.10.

Table 5.10 Sensitivity analysis of Xuanxia prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-1,801.09	62,340.61	126,482.34	190,624.08	254,765.80
NPV (Production)	37,871.46	82,176.89	126,482.34	170,787.80	215,093.25
NPV(Operation cost)	166,154.89	146,318.61	126,482.34	106,646.05	86,809.78

2) Xinglong

Through the economic evaluation of Xinglong prospect, we got the result that the NPV is 82,839.7×10^3 USD when the basic discount rate is 8%, and the NPV will be 62,623.7×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 44,750.18×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.11.

Table 5.11 Sensitivity analysis of Xinglong prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	10,980.75	27,865.47	44,750.18	61,634.90	78,519.62
NPV (Production)	21,424.19	33,087.19	44,750.18	56,413.19	68,076.19
NPV(Operation cost)	55,193.62	49,971.90	44,750.18	39,528.47	34,306.75

3) Jiyu

Through the economic evaluation of Jiyu prospect, we got the result that the NPV is 402,309.57×10^3 USD when the basic discount rate is 8%, and the NPV will be 291,001.78×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 207,050.73×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.12.

Table 5.12 Sensitivity analysis of Jiyu prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	35,887.15	121,468.94	207,050.73	292,632.52	378,214.34
NPV (Production)	88,820.71	147,935.71	207,050.73	266,165.80	325,280.84
NPV(Operation cost)	259,984.28	233,517.51	207,050.73	180,583.96	154,117.19

4) Liujiang

Through the economic evaluation of Xuanxia prospect, we got the result that the NPV is 80,172.52×10^3 USD when the basic discount rate is 8%, and the NPV will be 56,430.45×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 38,339.81×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.13.

Table 5.13 Sensitivity analysis of Liujiang prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-1,435.96	18,451.92	38,339.81	58,227.70	78,115.58
NPV (Production)	10,864.97	24,602.38	38,339.81	52,077.22	65,814.65
NPV(Operation cost)	50,640.75	44,490.28	38,339.81	32,189.33	26,038.87

5) Dacheng

Through the economic evaluation of Dacheng prospect, we got the result that the NPV is 476,732.7×10^3 USD when the basic discount rate is 8%, and the NPV will be 345,677.63×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 246,071.14×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.14.

Table 5.14 Sensitivity analysis of Dacheng prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	45,499.75	146,464.82	246,071.14	345,677.44	445,283.73
NPV (Production)	108,466.42	177,268.73	246,071.14	314,873.52	383,675.87
NPV(Operation cost)	307,679.03	276,875.09	246,071.14	215,267.20	184,463.24

6) Jiaozuo

Through the economic evaluation of Jiaozuo prospect, we got the result that the NPV is 398,596.69×10^3 USD when the basic discount rate is 8%, and the NPV will be 270,510.24×10^3 USD when the basic discount rate is 10%, while, the NPV will be 172,355.58×10^3 USD when the basic discount rate is 12%.The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.15.

Table 5.15 Sensitivity analysis of Jiaozuo prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-21,259.15	76,165.23	172,355.58	268,545.92	364,736.28
NPV (Production)	39,231.89	105,912.75	172,355.58	238,798.41	305,241.20
NPV(Operation cost)	231,850.65	202,103.11	172,355.58	142,608.05	112,860.49

7) Anyang-Hebi

Through the economic evaluation of Anyang-Hebi prospect, we got the result that the NPV is 213,009.91×10^3 USD when the basic discount rate is 8%, and the NPV will be 99,295.56×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 12,969.52×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.16.

Table 5.16 Sensitivity analysis of Anyang-Hebi prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-192,461.51	-88,494.76	12,969.52	114,433.04	364,736.28
NPV (Production)	-128,010.54	-57,116.35	12,969.52	83,054.65	153,140.13
NPV(Operation cost)	75,726.00	44,347.56	12,969.52	-18,409.29	-49,787.71

8) Yangquan

Through the economic evaluation of Yangquan prospect, we got the result that the NPV is 666,443.85×10^3 USD when the basic discount rate is 8%, and the NPV will be 513,717.87×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 397,954.47×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.17.

Table 5.17 Sensitivity analysis of Yangquan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	119,300.08	258,627.27	397,954.47	537,281.70	676,608.92
NPV (Production)	197,641.77	297,798.10	397,954.47	498,110.92	598,267.25
NPV(Operation cost)	476,296.19	437,125.35	397,954.47	358,783.63	319,612.80

9) Heshun-Zuoquan

Through the economic evaluation of Heshun-Zuoquan prospect, we got the result that the NPV is 573,727.91×10^3 USD when the basic discount rate is 8%, and the NPV will be 411,775.03×10^3 USD when the basic discount rate is 10%, while, the NPV will be 288,969.72×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.18.

Table 5.18 Sensitivity analysis of Heshun-Zuoquan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	8,784.18	148,876.97	288,969.72	429,062.57	569,155.29
NPV (Production)	87,556.34	188,263.03	288,969.72	389,676.49	490,383.20
NPV(Operation cost)	367,741.90	328,355.80	288,969.72	249,583.68	210,197.58

10) Lu‘an

Through the economic evaluation of Lu’an prospect, we got the result that the NPV is 474,119.52×10^3 USD when the basic discount rate is 8%, and the NPV will be 346,840.63×10^3 USD when the basic discount rate is 10%, while, the NPV will be 250,752.03×10^3 USD when the basic discount rate is 12%.The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.19.

Table 5.19 Sensitivity analysis of Lu‘an prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	40,119.52	145,435.77	250,752.03	356,068.30	461,384.58
NPV (Production)	99,337.34	175,044.67	250,752.03	326,459.43	402,166.82
NPV(Operation cost)	309,969.86	280,360.95	250,752.03	221,143.15	191,534.23

11) Jincheng

Through the economic evaluation of Jincheng prospect, we got the result that the NPV is 565,075.22×10^3 USD when the basic discount rate is 8%, and the NPV will be 431,417.04×10^3 USD when the basic discount rate is 10%, while, the NPV will be 329,520.52×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.20.

Table 5.20 Sensitivity analysis of Jincheng prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	110,846.00	220,183.25	329,520.52	438,857.78	548,195.03
NPV (Production)	172,324.77	250,922.62	329,520.52	408,118.43	486,716.28
NPV(Operation cost)	390,999.28	360,259.91	329,520.52	298,781.15	268,041.76

12) Huodong

Through the economic evaluation of Huodong prospect, we got the result that the NPV is 436,004.61×10^3 USD when the basic discount rate is 8%, and the NPV will be 328,954.25×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 247,334.03×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.21.

Table 5.21 Sensitivity analysis of Huodong prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	72,308.04	159,821.03	247,334.03	334,846.99	422,359.99
NPV (Production)	121,515.33	184,424.67	247,334.03	310,243.39	373,152.75
NPV(Operation cost)	296,541.33	271,937.67	247,334.03	222,730.39	198,126.73

13) Taiyuanxishan

Through the economic evaluation of Taiyuanxishan prospect, we got the result that the NPV is 283,056.04×10^3 USD when the basic discount rate is 8%, and the NPV will be 200,810.98×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 138,627.68×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.22.

Table 5.22 Sensitivity analysis of Taiyuanxishan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	16,159.85	77,393.77	138,627.68	199,861.61	261,095.51
NPV (Production)	50,590.81	94,609.23	138,627.68	182,646.14	226,664.58
NPV(Operation cost)	173,058.65	155,843.18	138,627.68	121,412.22	104,196.75

14) Huozhou

Through the economic evaluation of Huozhou prospect, we got the result that the NPV is 251,410.92×10^3 USD when the basic discount rate is 8%, and the NPV will be 190,334.15×10^3 USD when the basic discount rate is 10%, while, the NPV will be 142,972.66×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.23.

Table 5.23 Sensitivity analysis of Huozhou prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	33,206.56	88,096.01	142,972.66	197,849.29	252,725.92
NPV (Production)	64,075.72	103,524.18	142,972.66	182,421.14	221,869.58
NPV(Operation cost)	173,828.99	158,400.82	142,972.66	127,544.48	112,116.32

15) Ningwu

Through the economic evaluation of Ningwu prospect, we got the result that the NPV is 301,402.03×10^3 USD when the basic discount rate is 8%, and the NPV will be 230,562.53×10^3 USD when the basic discount rate is 10%, while, the NPV will be 176,676.61×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.24.

Table 5.24 Sensitivity analysis of Ningwu prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	74,093.35	125,384.99	176,676.61	227,968.24	279,259.86
NPV (Production)	102,933.90	139,805.24	176,676.61	213,547.96	250,419.34
NPV(Operation cost)	205,517.15	191,096.89	176,676.61	162,256.34	147,836.06

16) Fengcheng

Through the economic evaluation of Fengcheng prospect, we got the result that the NPV is 310,265.86×10^3 USD when the basic discount rate is 8%, and the NPV will be 179,144.82×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 79,449.56×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.25.

Table 5.25 Sensitivity analysis of Fengcheng prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-133,986.46	-25,885.13	79,449.56	184,784.24	290,118.89
NPV (Production)	-66,132.77	6,690.37	79,449.56	152,208.78	224,967.97
NPV(Operation cost)	144,600.56	112,025.06	79,449.56	46,874.09	14,298.59

17) Lianshao

Through the economic evaluation of Lianshao prospect, we got the result that the NPV is 312,989.53×10^3 USD when the basic discount rate is 8%, and the NPV will be 220,135.41×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 150,612.59×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.26.

Table5.26 Sensitivity analysis of Lianshao prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	1,769.76	76,191.18	150,612.59	225,034.03	299,455.47
NPV (Production)	47,800.46	99,206.51	150,612.59	202,018.67	253,424.78
NPV(Operation cost)	196,643.32	173,627.95	150,612.59	127,597.25	104,581.91

18) Enhong

Through the economic evaluation of Enhong prospect, we got the result that the NPV is 177,010.52×10^3 USD when the basic discount rate is 8%, and the NPV will be 88,378.07×10^3 USD when the basic discount rate is 10%, while, the NPV iwill be 21,449.62×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.27.

Table 5.27 Sensitivity analysis of Enhong prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-142,003.18	-59,099.89	21,449.62	101,568.70	181,687.70
NPV (Production)	-85,764.27	-31,639.57	21,449.62	74,538.85	127,628.04
NPV(Operation cost)	75,509.38	48,479.49	21,449.62	-5,580.24	-32,610.09

19) Baiyanghe

Through the economic evaluation of Baiyanghe prospect, we got the result that the NPV is 107,230.41×10^3 USD when the basic discount rate is 8%, and the NPV will be 70,551.35×10^3 USD when the basic discount rate is 10%, while, the NPV will be 42,709×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.28.

Table 5.28 Sensitivity analysis of Baiyanghe prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-22,202.53	10,527.15	42,709	74,890.86	107,072.70
NPV (Production)	-1,749.77	20,479.61	42,709	64,938.41	87,167.78
NPV(Operation cost)	62,613.92	52,661.47	42,709	32,756.53	22,804.08

20) Huhehu Depression

Through the economic evaluation of Huhehu Depression prospect, we got the result that the NPV is 99,831.77×10^3 USD when the basic discount rate is 8%, and the NPV will be 44,501.61×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 2,964.14×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.29.

Table 5.29 Sensitivity analysis of Huhehu Depression prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-99,456.97	-48,230.43	2,964.14	53,582.72	104,201.30
NPV(Production)	-67,726.40	-32,005.38	2,964.14	37,928.58	72,893.01
NPV(Operation cost)	34,272.45	18,618.29	2,964.14	-12,690.01	-28,344.16

21) Hegang

Through the economic evaluation of Hegang prospect, we got the result that the NPV is 117,461.25×10^3 USD when the basic discount rate is 8%, and the NPV will be 77,212.03×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 46,496.53×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.30.

Table 5.30 Sensitivity analysis of Hegang prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-27,732.16	9,382.18	46,496.53	83,610.89	120,725.24
NPV(Production)	-4,776.42	8,201.82	46,496.53	72,133.01	97,769.51
NPV(Operation cost)	69,452.28	57,974.41	46,496.53	35,018.66	23,540.78

22) Jixi

Through the economic evaluation of Jixi prospect, we got the result that the NPV is 150,007.52×10^3 USD when the basic discount rate is 8%, and the NPV will be 104,298.36×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 69,608.75×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.31.

Table 5.31 Sensitivity analysis of Jixi prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-9,544.78	30,031.97	69,608.75	109,185.51	148,762.27
NPV (Production)	14,934	42,271.37	69,608.75	96,946.13	124,283.52
NPV(Operation cost)	94,087.53	81,848.14	69,608.75	57,369.35	45,129.95

23) Shuangyashan

Through the economic evaluation of Shuangyashan prospect, we got the result that the NPV is 108,911.56×10^3 USD when the basic discount rate is 8%, and the NPV will be 72,339.84×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 44,534.56×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.32.

Table 5.32 Sensitivity analysis of Shuangyashan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-21,203.22	11,665.66	44,534.56	77,403.43	110,272.3
NPV (Production)	-873.35	21,830.58	44,534.56	67,238.51	89,942.44
NPV(Operation cost)	64,864.41	54,699.48	44,534.56	34,369.62	24,204.68

24) Boli

Through the economic evaluation of Boli prospect, we got the result that the NPV is 57,829.24×10^3 USD when the basic discount rate is 8%, and the NPV will be 24,857.19×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 136.29×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.33.

Table 5.33 Sensitivity analysis of Boli prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-79,625.24	-39,742.63	136.29	40,006.42	79,876.54
NPV(Production)	-54,957.28	-27,408.67	136.29	27,676.32	55,216.34
NPV(Operation cost)	24,796.53	12,466.42	136.29	-12,194.00	-24,527.97

25) Hongyang

Through the economic evaluation of Hongyang prospect, we got the result that the NPV is 106,667.1×10^3 USD when the basic discount rate is 8%, and the NPV will be 75,474.56×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 51,670.71×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.34.

Table 5.34 Sensitivity analysis of Hongyang prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-3.16	26,092.85	51,670.71	77,248.57	102,826.43
NPV (Production)	16,301.68	34,002.97	51,670.71	69,338.44	87,006.18
NPV(Operation cost)	67,490.97	59,580.85	51,670.71	43,760.58	35,850.44

(26) Fuxin

Through the economic evaluation of Fuxin prospect, we got the result that the NPV is 108,741.42×10^3 USD when the basic discount rate is 8%, and the NPV will be 80,967.46×10^3 USD when the basic discount rate is 10%, while ,the NPV will be 59,968.47×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.35.

Table 5.35 Sensitivity analysis of Fuxin prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	16,655.11	38,311.80	59,968.47	81,625.15	103,281.82
NPV (Production)	30,050.08	45,009.27	59,968.47	74,927.67	89,886.87
NPV(Operation cost)	73,363.43	66,665.95	59,968.47	53,270.99	46,573.51

27) Tiefa

Through the economic evaluation of Tiefa prospect, we got the result that the NPV is 113,620.29×10^3 USD when the basic discount rate is 8%, and the NPV will be 83,404.96×10^3 USD when the basic discount rate is 10%, while, the NPV iwill be 60,546.54×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.36.

Table 5.36 Sensitivity analysis of Tiefa prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	11,863.05	36,204.80	60,546.54	84,888.29	109,230.03
NPV (Production)	26,918.77	43,732.65	60,546.54	77,360.43	94,174.33
NPV(Operation cost)	75,602.25	68,074.39	60,546.54	53,018.68	45,490.84

28) Huainan

Through the economic evaluation of Huainan prospect, we got the result that the NPV is 324,912.49×10^3 USD when the basic discount rate is 8%, and the NPV will be 245,684.62×10^3 USD when the basic discount rate is 10%, while, the NPV will be 185,390.84×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.37.

Tab 5.37 Sensitivity analysis of Huainan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	66,759.08	126,074.97	185,390.84	244,706.72	304,022.58
NPV (Production)	100,111.56	142,751.18	185,390.84	228,030.49	270,670.15
NPV(Operation cost)	218,743.32	202,067.06	185,390.84	168,714.61	152,038.38

29) Huaibei

Through the economic evaluation of Huaibei prospect, we got the result that the NPV is 425,703.03×10^3 USD when the basic discount rate is 8%, and the NPV will be 313,420.75×10^3 USD when the basic discount rate is 10%, while, the NPV will be 228,159.13×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Table 5.38.

Table 5.38 Sensitivity analysis of Huaibei prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	18,689.44	123,424.29	228,159.13	332,893.96	437,628.81
NPV (Production)	77,580.34	152,869.72	228,159.13	303,448.52	378,737.96
NPV(Operation cost)	287,050.01	257,604.57	228,159.13	198,713.67	169,268.22

5.4. Evaluation of the Social Benefits from CBM Production in China

The development and utilization of CBM resources can contribute to the energy safety, the reduction of greenhouse gas emission and safe production of coal mines, and all these are so-called social benefits. The evaluation results of the social benefits can be taken as the base for financial subsidy evaluation, and then, we can provide proposals to the Chinese government on formulating the financial subsidy policies.

5.4.1. Contribution of CBM Production to Safe Production of Coal Mines

5.4.1.1. Effect of CBM Production on Reducing Gas Accidents of Coal Mines

CBM is the most serious threat to coal mining and easily results in serious tragedies. The coal consumption in China takes a large portion in the whole energy consumption struture. With the increase in coal production, more and more hazards have been caused by coal mine gas. According to the data publicized by the *State Administration of Work Safety*, the gas accidents in coal mines caused the death of 2,171 people in 2005, which is 36.6% of the total death of the mine accidents and 71% of the serious accidents. Compared with 2005, the deaths caused by the gas accidents in 2006 declined in some degree, but was still 27.8% of total death on coalmines. So reducing the gas accidents is one of key problems for improving production safety in the coal mines.

The effect of the CBM development and utilization for reducing the accidents is mainly reflected in the reduction of gas (methane) explosion accidents. The conditions of methane explosion consist of gas accumulation to a given content, fire sources with high temperature and enough oxygen. The gas content that can cause gas explosion when meeting fire is from 5% to 16%. When the gas concentration is less than 5%, it will not explode even when there is fire, but it can forms burning layer in periphery of the fire. The explosion power is the greatest under gas concentration of 9.5%. When the gas concentration is more than 16%, it will lose exploding ability, but it still can burn when there is fire. So if the gas concentration can be reduced to the safe range via the CBM development and utilization, the frequency of the accidents will decline.

5.4.1.2. Estimation of Contribution of CBM Production to Safety Production of Coal Mines

1) Estimation method

The methane in the coal is the cause of the accidents, so reducing the gas content through CBM development can decrease the occurrences of gas accidents and avoid the losses caused by the accidents. The main contribution of the CBM development to the safety production of coal mines can be viewed as avoiding accidents losses. Accordingly, the contribution of unit CBM production to the safety production can be estimated based on the following formula:

$$B_1 = E/C \tag{16}$$

In formula (16), B_1 refers to the contribution of producing $1m^3$ CBM to the production safety; E refers to the annual losses from the methane accidents in the evaluation year; C refers to the CBM quantity in the coal produced in the year.

2) Parameter estimation

a. Loss estimation

Direct economic losses are treated as the foundation for estimation of the contribution to the mining safety. According to the statistics of six major gas accidents from 2004 to 2006, the total direct economic loss was $21,804.62\times10^3$ USD, the total number of dead people is 439, the average direct economic loss of one death is about 496,794.9 USD. According to the data published by the Chinese State Administration of Safety Production Supervision and Management Bureau, in 2004, 2005 and 2006 China coal mine accidents, the number of dead people in gas accidents in coal mines were respectively 2185, 2171 and 1319. Accordingly, it can be assumed that the direct economic losses of the gas accidents in coal mines in these three years in China are respectively 105.06×10^6 USD, 103.8×10^6 USD, 63.29×10^6 USD, with an annual average of 91.14×10^6 USD (Table 5.39).

Table 5.39 China methane accidents direct losses and CBM contents

Year	2004	2005	2006	平均
Death toll	2,185	2,171	1,319	1,892
Direct losses (10^6 USD)	105.06	103.8	63.29	91.14
Coal production（10^9t）	1.997	2.011	2.325	2.144
CBM contents（10^9m^3）	14.978	15.92	17.438	16.08

b. Estimation of CBM quantity in coal production

CBM in coal production includes two parts: use and free vent. According to "The 11th

Five-Year Plan of CBM (coal mine gas) development and utilization ", free venting CBM in 2005 was around 15×10^9 m^3, among which 0.92×10^9 m^3 was extracted for use. Coalbed methane content from produced coal in 2005 was about 15.92×10^9 m^3. The output of produced coal in 2005 is 2.11×10^9 t, so the average coalbed methane content of one ton coal is 7.5 m^3/t. In 2004 and 2006, China's coal output was 1.997×10^8 t and 2.325×10^8 t, the coalbed methane content in produced coal in this two years were 14.978×10^9 m^3 and 17.438×10^9 m^3. In 2004, 2005 and 2006, the average coalbed methane content in produced coal is 16.112 ×10^9 m^3 (Table 5.39).

3) Evaluation result of social benefit

According to the estimated gas accident losses as well as the CBM quantity, we can estimate the contribution of CBM development to the safety production. The estimation value is about 0.0063 USD/m^3.

5.4.2. Contribution of CBM Production to Environmental Protection

5.4.2.1. Effect of CBM Production to Reduce Emission of Greenhouse Gas

In 30th October 2006, UK government issued the *Stern Report*. The information with scientific data in the report showed that if the temperature rose by 2°C, 15% ~ 40% of the species in the world would be extinct. If the temperature rose by 3°C, several millions of people would suffer from flood hazard. If the temperature rose by 4°C, it would influence the grain output of the world severely. The temperature rising could also result in sea-level rising and about 0.2 billion people could become homeless as “environmental refugees”. If the warming trend could not be changed, the world temperature would rise by 2°C ~3°C in fifty yeas in the future.

The harm from the greenhouse has been recognized by the world. On 16th February 2006, the *Kyoto Protocol* aiming at reducing the emission of greenhouse gas took effect. In terms of the *Kyoto Protocol*, all of the six contracting countries should control the emission of the six kinds of greenhouse gas: CO_2, CH_4, NO_2, HFCS, PFCS and SF_6. According to the *Kyoto Protocol*, the emission of the six greenhouse gases by the end of 2010 should be decreased by 5.2% of that in 1990 from all the developed countries, and there was no duty requirement for developing countries to reduce the emission.

CO_2 is the most important greenhouse gas at present and its discharge amount occupies more than 60% of the total greenhouse gas. Following CO_2, CH_4 is the second important greenhouse gas. Although the concentration of CH_4 in the air is lower, the growth rate is much higher. Furthermore, the GWP of CH_4 is 21 times higher than that of CO_2, so the influence of CH_4 is very serious in view of the greenhouse effect. Controlling the discharge of CH_4 is, therefore, very important to restrain greenhouse

Coal mining and utilization is one of the main activities accompanied by CH_4 emission. The CH_4 adsorbed in coal would be discharged into air in the processes of coal mining, surface treatment of coal, coal clean and selection, coal transportation and terminal utilization of coal. The contribution of CBM development and utilization to reducing CH_4 emission will come mainly from reducing the discharge amount of CH_4 in underground coal mining process.

5.4.2.2. Estimation of Contribution of CBM Production to Environmental Protection

1) Evaluation method

According to the *Clean Development Mechanism* (CDM), the following formula can be used to calculate the emission-reduction benefit from unit CBM exploitation.

$$B_2 = Q \times C_J \times \rho_J \times E_{J\text{-}E} \times E_{E\text{-}T} \times P_T \times R \times 10^{-3} \quad (18)$$

In the formula (18), the B_2 refers to the emission-reduction benefit, USD; Q refers to the CBM production, m^3; C_J denotes the average content of CH_4; ρ_J refers to the concentration content of CH_4 in standard condition, g/L; $E_{J\text{-}E}$ refers to the quality reduction factor between CH_4 and CO_2 in case of producing equal greenhouse effect; $E_{E\text{-}T}$ refers to the quality reduction factor between CO_2 and C in CO_2; P_T refers to the price of C index, USD/t; R refers to the standard exchange rate of USD to CNY, CNY/USD.

2) Parameter Estimation

a. CH_4 content

The CBM produced by means of surface extraction contains other impurities, and it needs purified before sale. Generally, the commodity rate of CBM is 95%, and therefore, the content of CH_4 is set to 93% in this research.

b. CH_4 density

The standard methane density is 0.717 g/L in this research.

c. The mass conversion coefficient between CH_4 and CO_2

The CBM produced from the surface drilling is mainly used as rsidence and industrial fuels. CBM burning will produce CO_2 which will be directly discharged into air under the present conditions, so this part of CO_2 should not be considered in calculating the mass conversion coefficient between CH_4 and CO_2. In case of no burning, the mass conversion coefficient is 21 under the same greenhouse effect. In case of burning, the mass of the generated CO_2 can be obtained from multiplying the CH_4 mass by 44/16, and 44/16 is the molecular mass ratio between CH_4 and CO_2, so, the mass conversion coefficient between CH_4 and CO_2 is 18.25.

d. The mass conversion coefficient between CO_2 and C

The mass of C can be obtained from multiplying CO_2 quality by 12/44.12/44 is the molecular mass ratio between C and CO_2.

e. The price of C index.

The current national price of C index is in the range of 5 USD/t~10 USD/t. In this research, the medium value (7.5 USD/t) will be used.

f. Exchange rate

The exchange rate of USD to CNY is set to 7.9 according to the contract.

3) Results of benefit estimation

According to formula (17) and parameter estimation results, the unit benefit from CBM development and utilization in reducing the greenhouse gas emission is about 0.025 USD/m^3.

5.4.3. Contribution of the CBM Production to Energy Safety

5.4.3.1. Effect of CBM Production to Chinese Energy Safety

With the development of national economy, the oil and gas consumption in China is increasing. In 2006, the importation of crud oil is 2.9×10^6 barrels per day and the importation of refined oil is 1×10^6 barrels per day, and the net oil importation takes almost half of the total oil consumption. In the "11th Five Years Plan", the oil consumption will heavily rely on foreign supply instead of on domestic supply. The heavy foreign dependence means severe challenges in oil supply safety. In order to give rational reactions to the fierce fluctuation of international oil market, to improve the reaction capacity of dealing with unexpected events and to guarantee the national oil safety, the construction of strategy oil reserve is necessary.

The utilization of CBM is similar to natural gas, and CBM can substitute oil in some fields, so it is one of the alternative energy to replace oil. Benefiting from the mature petroleum industry, we have complete technology system for CBM development, and the vertical well drilling technology is already standardization and systematization. CBM is the most realistic gas resources with huge development potential in near future. The tension in oil and gas deficiency can be reliably relieved. The main effect of CBM development and utilization to Chinese energy safety can be mainly reflected in substituting oil and reducing strategy oil reserves.

5.4.3.2. Contribution Evaluation of the CBM Production to Chinese Energy Safety

1) Estimation method

The direct benefit of CBM long term stable development can be regarded as reducing the strategy oil reserve and decreasing reserving cost. So, the contribution of CBM development to Chinese energy safety can be estimated according to he following formula:

$$B_3 = Q \times C_s \times R \times E_{t\text{-}b}/E_{o\text{-}g} \quad (19)$$

In formula (19), B_3 refers to the benefit of CBM development to Chinese energy safety, USD; Q refers to the CBM production, m^3; C_s refers to the cost of oil reserve, USD/ barrel; R refers to the exchange rate between US dollars and CNY, CNY/USD; Et_{-d} refers to conversion coefficient of crude oil measurement unit, barrel/ton; E_{o-g} refers to conversion coefficient of oil equivalent, m^3/t.

2) Paremeters estimation

a. Oil reserve cost

Oil reserve cost includes infrastructure cost, operation and management cost, oil filling / further oil filling cost and oil extraction cost. The oil reserve in China is only at the initial stage, and it is lack of related reserve cost data, so we take the oil reserve cost data of Asia-Pacific area published by PB-KBB as the basic data. At present, the oil reserves are mostly in ground storage tanks. In this research, we will estimate the oil reserve cost according to the data published by PB-KBB in 1998. In the model designed by PB-KBB company, the parameters are set as follows: reserved capacity is 100×10^6 barrels, the period was 40 years, the fundamental cost is 15.68 USD per berral, the operation and management cost is 0.16 USD/per berral/year, the oil filling and further oil filling cost is 0.05 USD per berral, and the oil extraction cost is 0.07 USD per berral. If the CBM supply from a prospect is converted to oil equivalent according to the oil-gas equivalent, and supposing that the annual production is 100×10^6 barrels and the stable production period is 40 years, an oil reserve tank of the same scale can be saved. In this way, we can get that the average infrastructure cost is (15.68÷40)USD/berral/year, and the operation cost is 0.16 USD/berral. The annual injection and extraction cost is too low to be considered. So, the annual oil reserve cost is ((15.68÷40)+0.16)USD/berral/year [20]. According to the inflation between 1998~2006 in America, the oil reserve cost in 2006 is estimated to 0.69 USD/berral/year.

b. Other paremeters

The exchanged rate of US dollars to CNY is set to 7.9; the conversion between ton and berral is set to 7.3 according to the international average standard and the oil equivalent is set to 1,225 m^3/t.

3) Results of benefit estimation

According to formula (19) and parameter estimation results, the unit benefit from CBM development and utilization as energy safety contribution is about 0.0038 USD/m^3.

5.5. Selection of the Favorable CBM Prospects in China

In the selection of the favorable CBM prospects, we should not only lay stress on the economic value from the CBM development, but its value as a kind of strategic resources should also be taken into account. In this research, the NPV and CBM-bearing area are selected as the indices for optimal selection of the favorable CBM prospects. Based on the economic evaluation results under the mere vertical well plan and CBM-bearing area, the prospects with good economic results and large resource potential will be selected as the favorable CBM prospects. Through further analysis of the selected favorable prospects, we take one of them as a pilot test.

5.5.1. Main Economic Indices and Optimal Ranking Method

5.5.1.1. Main Economic Indices

1) NPV

NPV is the basic index for the optimal ranking of CBM prospects. It is the accumulation of all of the present values discounted in a certain rate from the net cash flows applied during the evaluation period. It can reflect the economic value of a CBM development project. NPV>0 means that excessive profit can be achieved from development of such a CBM prospect, and NPV=0 reflects only the lowest expected profit from the CBM prospect development, while NPV<0 indicates we could not get ideal profit from the prospect development

2) Geological reserves

The geological condition and market condition of a CBM prospect have been reflected in the index NPV. The CBM resource condition could be expressed by geological reserves. The geological reserves can not only determine the development scale but also reflect the strategic value of the CBM resources.

5.5.1.2. The Methods for Ranking and Optimal Selection of CBM Prospects in China

1) Method for ranking CBM prospects in China

Without considering possible shortage of capital available, ranking according to the NPV can ensure most economic profit. Firstly, sequencing the CBM prospects with NPV>0 when basic discount rate is 12%. Secondly, sequencing the CBM prospects with NPV<0 when discount rate is 12% and the CBM prospect with NPV>0 when discount rate is 10%. Thirdly, sequencing the CBM prospect with NPV<0 when discount rate is 10% and the CBM prospect with NPV>0 when discount rate is 8%. Finally, sequencing the CBM prospect with NPV<0 when discount rate is 8%.

The ranking result based on NPV also needs adjustment in accordance with the size of geological reservoir; that is to say, the ranking result will be grouped on the basis of the classification of geological reservoir. According to the division standard of CBM reserves, sufficiency in *CBM resources reserves*, the CBM reserves grade of Chinese CBM prospect can be classified as shown in Table 5.40.

Table 5.40 Grade division of China CBM geological reservoir

Geological reservoir (10^9m^3)	Grade
≥300	Super huge
30~300	Huge
3~30	Middle-size
<3	Small-size

2) Optimal selection method of Chinese CBM prospects

a. Optimal selection of Chinese CBM prospects in present industry policy

According to the ranking result, the CBM prospects can be divided into priority development, low-priority development, market exploitation or technical research and development, economic margin, future development and further investigation needed. Detailed criteria are as shown in Table 5.41.

Table 5.41 Comprehensive grading criteria of Chinese CBM prospect

Grading	Development decision	NPV	Geological reservoir (10^9m^3)
A	Priority development	NPV（i=12%）≥0	≥300
B	Low-priority development	NPV（i=12%）≥0	<300
C	Development possible after technical research	NPV（i=12%）<0，NPV（i=10%）≥0	≥30
D	Economic margin	NPV（i=12%）<0，NPV（i=10%）≥0	<30
		NPV（i=10%）<0，NPV（i=8%）≥0	≥30
E	Development impossible for the time being	NPV（i=10%）<0	<30
		NPV（i=8%）<0	30~300
F	Further research required for decision	NPV（i=8%）<0	≥300

b. Further financial support needed for selection of CBM prospects

CBM development has the characters of marked social benefits and lower economic profits at the early stage of development, so favorable government policy is needed to promote the formation and development of CBM industry. At present, Chinese CBM development has got very favorable tax policy and some government subsidy, which have been expressed in the calculation of NPV. There is little space for tax derating, so we need to analyze the extent of government subsidy. According to the estimation of social benefit of CBM production, the contribution to coal mine safety production, greenhouse gas emission reduction and energy security is 0.032 USD/m^3. On this basic, we will analysis the effect of 0.0063 USD government subsidies to the result of economic evaluation and find the prospects which need government financial subsidy.

5.5.2. Comprehensive Ranking and Optimal Selection of Chinese CBM Prospects

5.5.2.1. Comprehensive Ranking of Chinese CBM Prospects

According to the classification of geological reserves of CBM prospects, the comprehensive ranking result for each grade are shown in Table 5.42, Table 5.43, Table 5.44.

Table 5.42 Comprehensive ranking for super huge CBM prospects

Number	1	2	3	4	5	6
Prospect	Yangquan	Jincheng	Heshun-Zuoquan	Lu’an	Huodong	Dacheng
Number	7	8	9	10	11	12
Prospect	Huainan	Hancheng	Zhina	Liupanshui	Fugu	Guiyang
Number	13	14	15		16	17
Prospect	Sanjiaobei	Liulin	Jura in Ordos Basin		Xuanwei	Xingyi

Table 5.43 Comprehensive ranking for huge Chinese CBM prospects

Number	1	2	3	4	5	6
Prospect	Huaibei	Jiyu	Ningwu	Jiaozuo	Lianshao	Huozhou
Number	7	8	9	10	11	12
Prospect	Taiyuanxishan	Xuanxia	Fengcheng	Jixi	Hongyang	Shuangya-shan
Number	13	14	15	16	17	18
Prospect	Baiyanghe	Enhong	Anyang-Hebi	Huhehuo Depression	Boli	Fengfeng
Number	19	20	21	22	23	24
Prospect	Tianfu	Tongchuan	Xiangning	Songzao	Huolinhe	Qianxibei

5.5.2.2. Selection Results of the Favorable CBM Prospects in China

1) Selection results of the favorable CBM prospects under the present industry policy

According to the criteria for selection of the favorable CBM prospects, the CBM prospects are divided into 6 different decision classes under the present industry policy. The results are summarised in Table 5.45.

Table 5.44 Comprehensive ranking for middle-size CBM prospects

Rank	1	2	3	4	5	6
Prospect	Tiefa	Fuxin	Hegang	Xinglong	Liujiang	Daqingshan
Rank	7	8	9	10	11	12
Prospect	Lingshan	Kailuan	Lincheng	Hongmao	Rujigou	Zhuozishan
Rank	13	14	15	16	17	18
Prospect	Hulusitai	Shizuishan	Leping	Eiweiergou	Luocheng	Guishan
Rank	19	20				
Prospect	Libixia	Heshan				

Table 5.45 Selection of the favorable CBM prospects under the present industry policy

Grading	Development Decisions	CBM prospects
A	Development with top priority	Yanquan, Jincheng, Heshun-Zuoquan, Lu'an, Huodong, Dacheng, Huainan, Hancheng
B	Development with priority	Huaibei, Jiyu, Ningwu, Jiaozuo, Lianshao, Huozhou, Taiyuanxishan, Xuanxia, Fengcheng, Jixi, Tiefa, Fuxin, Hongyang, Hegang, Xinglong, Shuangyashan, Baiyanghe, Liujiang, Enhong, Daqingshan, Anyang-Hebi, Lingshan, Kailuan, Lincheng, Huhehu Depression, Boli
C	Development possible after technical research	Fengfeng, Zhina, Liupanshui
D	Economic margin	Hongmao, Fugu, Guyang, Sanjiaobei,Liulin
E	Development impossible for the time being	Ruijigou, Zhuozishan, Hulusitai, Shizuishan, Leping, Aiweiergou, Luocheng, Tianfu, Guishan, Libixia, Heshan, Tongchuan, Xiangning, Songzao, Huolinhe, Qianxibei
F	Further research required for decision	Jura, Xuanwu and Xingyi

2) Prospects which need further financial support

When given subsidy of 0.0063 USD, the following prospects will be of certain economic benefit, as shown in Table 5.46.

Table 5.46 Prospects which need further financial support

Prospect	Current fiscal policy		Subsidy increased to 0.28 CNY		ΔNPV (10^3USD)
	NPV（i=12%）（10^3USD）	Grading	NPV（i=12%）（10^3USD）	Grading	
Fengfeng	-30,221.6	C	43,020.46	B	73,242.08
Liupanshui	-45,175.4	C	12,135.13	A	57,310.54
Zhina	-43,047.1	C	14,327.62	A	57,374.75
Hongmao	-6,378.18	D	10,734.22	B	17,112.41

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Chapter 6 Introduction to Favorable CBM Prospects and Pilot Test Proposals in China

For the economic optimization, we know that the first priority development and secondary priority development CBM prospects are economically beneficial areas, which are worthy of further work. In theses CBM prospect, we will select the prospects we have a better understanding of, which have good geological and market conditions and without any pilot test done there. The further pilot tests will provide the local large-scaled development with valuable geological data, production data and development experiences.

6.1. The Introduction to Favorable CBM Prospects in China

6.1.1. The Favorable CBM Prospects of North China

6.1.1.1. Yangquan Prospect of North China

The Yangquan prospect is located in the Yangquan city of Shannxi Province and is between the Taiyuan and Shijiazhuang city. It is warm and semi-humid continental monsoon climate with four distinct seasons, substantial sunshine and large change of diurnal temperature. Furthermore, the traffic of the area is very convenient and the railways and highways are developed.

The market condition of Yangquan prospect is better and the neighbouring Taiyuan and Shijiazhuang city have developed economy, a dense population and strong demand for clean energy. Besides, West-East transportation natural gas pipeline and Shaanxi-Beijing natural gas pipeline provide favorable transportation facilities for the large-scale commercial development of Yangquan prospect.

In the economic evaluation of Yangquan prospect, when the gas price is 0.13 USD/m^3, the subsidy is 0.026 USD/m^3, the standard discount rate is 12% , the evaluation period is 31 years (the conditions of the following prospects are the same) and the single-well productivity in the stable production period is 2,718 m^3/d, pointing to the sales of Yangquan, Taiyuan and Jinzhong city and the out-transportation by West-East transportation and Shaanxi-Beijing natural gas pipelines, the development financial NPV is 397,954.5×10^3 USD.

6.1.1.2. Jincheng Prospect of North China

The Jincheng prospect is located in the southern Qinshui Basin of Shanxi Province which is mainly the hills and mountains, and the elevation of which is between 600 m and 1,000 m. The Jincheng prospect is continental climate , where the change in diurnal temperature is greater, the average temperature is 11.7℃， frost period is between November and march of second year, and the maximum thickness of frozen earth is 42cm [1]. Furthermore, the traffic of the area is very convenient and the railways and highways are developed.

The CBM market condition of Jincheng prospect is better, and in the Shanxi Province which belongs to and the neighbouring Henan and Hebei Province, the supply and demand gap of natural gas is larger. From the the local actual sale situation, the Jincheng Group has sold the CBM from the Jincheng prospect to the Jincheng, Changzhi,Taiyuan of Shanxi Province and Zhengzhou, Jiaozuo, Kaifeng of Henan Province [2]. Besides, West-East transportation natural gas pipeline, Shaanxi-Beijing natural gas pipeline and Duanshi-Jincheng-Boai natural gas pipeline which are being built by China United Coalbed Methane Corporation Limited (China CBM) provide favorable transportation condition for the large-scale commercial development of Jincheng prospect.

In the economic evaluation of Jincheng prospect, when the single-well productivity in the stable production period is 2,278 m^3/d, pointing to the sales of Jincheng city and the out-transportation by West-East transportation pipeline and Shaanxi-Beijing natural gas pipeline, the development financial NPV (net present value) is 329,520.5×10^3 USD.

The Jincheng prospect has the best geological condition and the most concentrated activities, and the substantial exploration and small-scale commercial development indicate that the Jincheng prospect is one of the most favorable areas in the CBM exploration and development of China at present.

6.1.1.3. Heshun-Zuoquan Prospect of North China

The Heshun-Zuoquan prospect is located in the Heshun and Zuoquan County in the middle of Shanxi Province. In the prospect the transportation mainly depends on the Yangquan-Licheng highway running through it. The most villages and towns have low-class road network, but in partial mountain areas roads are not well developed.

The market of Heshun-Zuoquan prospect is in Shanxi Province and neighbouring Henan, Hebei Province, and the supply and demand gap of natural gas is great. Besides, West-East transportation natural gas pipeline and Shaanxi-Beijing natural gas pipeline provide favorable transportation facility for the large-scale commercial development of Heshun-Zuoquan prospect.

In the economic evaluation of Heshun-Zuoquan prospect, when the single-well productivity in the stable production period is 1,385 m^3/d, pointing to the sales of Yangquan, Taiyuan, Jinzhong city and the out-transportation by West-East transportation and Shaanxi-Beijing natural gas pipelines, the standard discount rate is 12%, and the evaluation period is 30 years, the development financial NPV is 288,969.7×10^3 USD.

Heshun-Zuoquan’s target market is overlapped with the market of Yangquan, and its position is lower in ranking. Therefore, in the development decision-making, the market share of Yangquan should be taken into account. When the target market has been shared by Yangquan, the economic benefits of the area will be lower than the economic evaluation in this research. More efforts should be made to exploring market in order to increase economic benefits.

6.1.1.4. Lu’an Prospect of North China

The Lu’an prospect is located in the east of Qinshui Basin of Shanxi Province and is in undulating and hilly topography. In the prospect the climate is continental climate and the change in diurnal temperature is great. Besides, the transportation facilities are well developed with convenient access to railways and highways.

The market potential of Luan prospect is strong and in the Shanxi Province and the neighbouring Henan, Hebei Province, the supply and demand gap of natural gas is larger. Besides, West-East transportation natural gas pipeline and Shaanxi-Beijing natural gas pipeline provide favorable transportation condition for the large-scale commercial development of Luan prospect.

As for the economic evaluation of Luan prospect, when the single-well productivity in the stable production period is 2,129 m^3/d, and the CBM is to be sold in Changzhi, Jincheng, Jiaozuo, Zhengzhou city and is transported by West-East transportation and Shaanxi-Beijing natural gas pipelines, the development financial NPV is 250,752×10^3 USD.

Lu'an’s target market is overlapped with Jincheng’s market, and Lu’an’s position is low in ranking. Therefore, when the demand of the local and adjacent market is insufficient, pipeline transmission should be considered to enhance economic benefits.

6.1.1.5. Huodong Prospect of North China

The Huodong perpective is located in the east foot of Huoshan mountain in the middle-south Shanxi Province across Pingyao county, Qinyuan county of Changzhi city, Gu county and Anze county of Linfen territory. Its terrain is very complex with a high north-low south-high hypsography. In the prospect the main traffic way is highway and in the villages and towns there are also connected low-rank roads.

The market condition of Huodong prospect is better and in the Shanxi Province and the neighbouring Henan, Heber Province, the supply and demand gap of natural gas is larger. Besides, West-East transportation natural gas pipeline and Shaanxi-Beijing natural gas pipeline provide favorable transportation condition for the large-scale commercial development of Huodong prospect.

In the economic evaluation of Huodong prospect, when the single-well productivity in the stable production period is 2,114 m^3/d, pointing to the sales of Linfen, Taiyuan city and the out-transportation by West-East transportation and Shaanxi-Beijing natural gas pipelines, the development financial NPV is 247,334×10^3 USD.

Taiyuan is the potential market for Huodong, Yangquan and Heshun-Zuoquan, when the lmarket is occupied, adoption of Pipeline transmission should be considered to increase economic benefits, on the basis of taking full advantage of Linfen market.

6.1.1.6. Dacheng Prospect of North China

The Dacheng prospect is located in the hinterland of the North China Plain, 70 kilometers away from Tianjin in the east and 160 kilometers away from Beijing in the north. Dacheng prospect has easy access to roads and it is crossed by Langfang-Botou and Tianjin-Baoding road and has complete road network covering counties and villages.

In Dacheng prospect the economy is well developed and the population is dense, so it has a large demand for the CBM. Besides, the Shaanxi-Beijing natural gas pipeline provides favorable transportation facilities for the large-scale commercial development of Dacheng prospect.

In the economic evaluation of Dacheng prospect, when the single-well productivity in the stable production period is 2,275 m^3/d, and when the market tend to be Tangshan, Langfang city and the transportation is conducted by Shaanxi-Beijing natural gas pipeline, the development financial NPV is 246,071.1×10^3 USD.

6.1.1.7. Hancheng Prospect of North China

Hancheng prospect is located in the middle of Shaanxi Province or the middle-south of Qinshui Basin. The prospect extends to Huanghe in the northeast, and neighbours to Chenghe mining area in the southwest. The transportation facilities are sufficient and the railways ans roads are well developed in the Hancheng prospect.

Hancheng prospect has not been commercially developed, but Hancheng City and the region near Xian City have great CBM consumption potential. Besides, the West-East transportation natural gas pipeline provides favorable CBM transportation condition for the large-scale business development of Hancheng prospect.

In the economic evaluation of Hancheng prospect, when the single-well productivity in the stable production period is 2,029 m^3/d, and when the market is expected to be Hancheng, Xian, Weinan city and the out-transportation by west-east transportation natural gas pipeline, the development financial NPV is 57,757.11×10^3 USD.

6.1.1.8. Jiyu Prospect of North China

Jiyu prospect cover the area between Tangshan and Tianjin and has a hypsography which is high in the north north and low in the south. The climate there belongs to south temperate zone of semi-arid climate with hot and wet summers and cold and dry winters. In the Jiyu prospect, the transportion conditions are good and Jingshan and Jingqin road runs across it and has a complete road network.

In Jiyu prospect the economy is developed and the population is dense, so it has a large demand for the CBM. Besides, the Shaanxi-Beijing natural gas pipeline provides favorable transportation condition for the large-scales commercial development of Jiyu prospect.

In the economic evaluation of Jiyu prospect, when the single-well productivity in the stable production period is 1,913m^3/d, and the market tends to be Tangshan and the CBM is out-transported by Shaanxi-Beijing natural gas pipeline, the development financial NPV is 207,050.7×10^3 USD.

Tangshan is one of the potential markets of Dacheng, and Jiyu's rank is higher than Dacheng in ranking. Therefore, in the development of a prospective, we should take full advantage of the socio-economic development of the region and further develop the local market to increase economic benefits.

6.1.1.9. Ningwu Prospect of North China

Ningwu basin covers Ningwu, Yuanping, Shenchi, Jingle, Loufan and Lan County of Xinzhou city in Shanxi Province and belongs to intermountain structure basin [2]. The prospect has temperate continental climate with long and cold winter, drouthy and rainless spring and warm and rainy summer. The roads in the region are well developed inlcuding railways and highways. The Xinzhou is a neightbour town of Taiyuan city just 75km away from Taiyuan and the traffic is very convenient in the Xinzhou crossed by Jingyuan, Beitongpu railways and national highway 108. Presently, the China National Petroleum Corporation is carrying out CBM exploration work in the south of Ningwu Basin.

No commercialized development is conducted in Ningwu prospect yet. Since it is in Xinzhou, near Datong and Suozhou, there is potential maeket for clean energy. Besides, the CBM resources of it can also be transported by Shaanxi-Beijing CBM pipelines.

In the economic evaluation of Ningwu prospect, when the single-well productivity in the stable production period is 2,464 m^3/d, pointing to the sales of Datong, Suzhou city and the out-transportation by Shaanxi-Beijing natural gas pipeline, the development financial NPV is 176,676.6×10^9 USD.

6.1.1.10. Jiaozuo Prospect of North China

The Jiaozuo prospect is located in Jiaozuo City in south coal-bearing region at the foot of Taihangshan Mountain of Henan Province. It is warm temperate zone with warm subhumid and semiarid climate, and with abundant sunshine and rainfall. Transportation is good and is crossed by four railways (Jiaozuo-Zhicheng, Jiaozuo-Taiyuan, Jiaozuo-Xinxiang, and Yueshan-Houma). Presently, Henan Province has established Henan Provincial Coal Seam Gas Development and Utilization Co., LTD to carry out CBM exploration work in Jiaozuo.

Jiaozuo prospect has not been commercially developed, but it is in Jiaozuo City, near the Zhengzhou City and Shanxi Province, and there is a great demand for clean energy in the region and a great CBM market potential. Besides, the CBM resources in the prospect can also be transported by West-East transportation CBM pipeline to other places.

In the economic evaluation of Jiaozuo prospect, when the single-well productivity in the stable production period is 2,154 m^3/d, and the ,expected market is in Jiaozuo, Zhengzhou, Jincheng and carried to other places by West-East transportation natural gas pipeline, the development financial NPV is 172,355.6×10^3 USD.

The target markets of Jiaozuo are overlapped with that of Jincheng and Lu'an,and its rank in comprehensive ranking is lower. Therefore, in the development of the prospective, more attention should be paid to the location advantages, making full use of Huozhou market. The alternative is to use pipeline transmission to explore other markets.

6.1.1.11. Huozhou Prospect of North China

The Huozhou prospect is located in the middle-south Shanxi Province, crosses through four counties and cities (Huozhou, Fenxi, Hongtong, Puxian), and has a high north-low south hypsography which mainly is low hills and upland. In the prospect, the transportation conditions are good and it is crossed by Nantongpu railway and national highway 108.

The market for of Huozhou prospect is better than average, potentially in the Shanxi Province and the neighbouring Henan, Hebei Province, where the supply and demand gap of natural gas is large. Besides, Shaanxi-Beijing natural gas pipeline provides favorable CBM transportation condition for the large-scaled commercial development of Huozhou prospect.

In the economic evaluation of Huozhou prospect, when the single-well productivity in the stable production period is 2,108 m^3/d, the CBM is sold to Huozhou, Linfen, Jinzhong and out-transported by Shaanxi-Beijing natural gas pipeline, the development financial NPV is 142,972.7×10^3 USD.

Linfen and Jinzhong are potential markets of some other prospectives whose ranka are higher than Huozhou in the integrated ranking. Therefore, in the development of the target area, more attention should be paid to the location advantages, making full use Huozhou market, and using pipeline transmission to explore other markets.

6.1.1.12. Taiyuan Xishan Prospect of North China

Xishan prospect in Taiyuan is located in the east foot of Luliang Mountain and west of the Taiyuan basin in the middle of Shanxi Province, connected to convenient railways and highways.

Xishan prospect have not CBM commercialized sale, but it is close to some big cities (Taiyuan, Shijiazhuang etc.) and West-East transportation natural gas pipeline and Shaanxi-Beijing natural gas pipeline, and therefore it has a potential market.

In the economic evaluation of Taiyuan Xishan prospect, when the single-well productivity in the stable production period is 2,108 m^3/d, and the market is expected to be Taiyuan and the CBM is carried to other places by Shaanxi-Beijing natural gas pipeline, the development financial NPV is 138,627.7×10^3 USD.

Taiyuan is the target market of Yangquan and Jincheng, and the latter's rank is higher. Therefore, in the development of these target areas, much effort should be made to the use of transmission pipelines to enhance economic benefits.

6.1.1.13. Xuanxia Prospect of North China

Xuanxia prospect is located in Zhangjiakou City and the topography is complex with many mountains, hills and basin valleys. It has continental climate with four distinct seasons, a big change of diurnal temperature, cold winter and cool summer. The traffic condition is good in Zhangjiakou with easy access to two railways (Beijing-Baotou, Datong-Qinhuangdao) and three national highways (110, 112, and 207).

Xuanxia prospect has not been commercially developed, but it is in Zhangjiakou City and so the region has a strong demand for clean energy and a great CBM market potential. Besides, the CBM resources here can also be transported by Shaanxi-Beijing CBM pipelines to other regions.

In the economic evaluation of Xuanxia prospect, when the single-well productivity in the stable production period is 2168m^3/d, and the expected market is in Zhangjiakou and the CBM can be transported by the Shaanxi-Beijing natural gas pipeline, the development financial NPV is 126,482.3×10^3 USD.

Xuanxia target area has not been commercially developed, but it is located in the city of Zhangjiakou, which has a strong demand for clean energy. It is a vast potential CBM market.
Tangshan is one of the target markets of Dacheng target area, and Dacheng's rank is high. Therefore, when the demand of Tangshan market is insufficient, Dacheng should take advantages of its location to make full use of Zhangjiakou market and explore new markets actively.

6.1.1.14. Xinglong Prospect of North China

Xinglong prospect is located in Chengde and the transition zone between North China and Northeast China. The prospect is in cold temperate zone and the climate is transitionary continental monsoon from semiarid to subhumid with four distinct seasons, with synchronous rainfall and heat and vast variation in temperature between days and nights. Chengde is a territorial central city which connects the North China, Northeast China and Northwest China and the Chengde has well developed railways and roads.

The prospect has not been commercially explorated for CBM, but the Jingjintang area which is located in and near Tangshan, Qinhuangdao, Zhangjiakou has a strong demand for clean energy, so the CBM market potential is great.

In the economic evaluation of Xinglong prospect, when the single-well productivity in the stable production period is 2,615 m^3/d, and the market is expected to be Tangshan, the development financial NPV is 44,750.18×10^3 USD.

Xinglong target area has a low rank, and its target markets overlap with Dacheng and Jiyu. Therefore, when the demand of Tangshan market is insufficient, Xinglong should make full use of the advantages of its socio-economic development, open up new markets, in order to ensure economic benefits.

6.1.1.15. Liujiang Prospect of North China

Liujiang prospect is located in Liujiang basin in the north of the Qinhuangdao, high in the north and low in the south. The prospect has warm temperate subhumid continental monsoon climate with warm climate. The area has good transportation conditions with Jingshen, Jingqin, Daqin railways and the 102, 105 highways available and Qinhuangdao nearby is a transportation centre.

The Liujiang prospect has not been commercially developed, but the Jingjintang area where the prospect is located has a dense population, developed economy and much demand for clean energy, so the CBM market potential is great. Besides, the CBM in the prospect can be transported by Shaanxi-Beijing pipelines.

In the economic evaluation of Liujiang prospect, when the single-well productivity in the stable production period is 1998 m^3/d, and the market is expected to be Qinhuangdao and the CBM is transported by Shaanxi-Beijing natural gas pipeline, the development financial NPV is 38,339.81×10^3 USD.

6.1.2. The Favorable CBM Prospects of East China

6.1.2.1. Huainan Prospect of East China

Huainan prospect is located in the middle of Anhui Province and the area mainly belongs to undulating topography. In the prospect the climate is mild with four distinct seasons and abundant rainfall and the rail and highway transportation is well developed.

Huainan prospect has not been commercially developed, but it has a favorable geographical position, developed economy, dense population, and a large demand for the clean energy, so the market potential is very great.

In the economic evaluation of Huainan prospect, when the single-well productivity in the stable production period is 2,182 m^3/d, and the market is expected to be in Huainan and Bengfu, the development financial NPV is 185,390.8×10^3 USD.

6.1.2.2. Huaibei Prospect of North China

Huaibei prospect is located in the middle of Anhui Province, connecting the Jiangsu Province in the north and Henan Province in the west. The prospect has convenient transportation facilities with developed roads, the Longhai, Jinghu, Jingjiu, Xufu railway also across the prospect. Presently, the Huaibei Coalfield Group is generating electricity by utilizing underground CBM extraction and it is carrying out experiments of surface drilling extraction and drilling extraction in extracted area.

Huaibei prospect has not been commercially developed, but it has a favorable geographical position, developed economy, dense population, and a large demand for the clean energy, so the market potential of it is very great.

In the economic evaluation of Huaibei prospect, when the single-well productivity in the stable production period is 2,299 m^3/d, and the market is expected to be Huaibei, Xuzhou and Suzhou, the development financial NPV is 228,159.1×10^3 USD.

6.1.3. The Favorable CBM Prospects of Northeast China

6.1.3.1. Jixi Prospect of Northeast China

Jixi prospect is located in the southeast Heilongjiang Province and has well developed transportation conditions with developed roads. At present, Jixi Filiate of Longmei Coalfield Group is carrying out synthetical underground CBM utilization activities and Jixi Coalfield Group is using the underground extraction CBM to generate electricity.

The Jixi prospect has favorable market potential of CBM utilization and Jixi, Qitaihe of which the fuel is mainly coal in the prospect has a strong demand for the clean energy.

In the economic evaluation of Jixi prospect, when the single-well productivity in the stable production period is 2,029 m^3/d, sold to Qitaihe and Jixi, the development financial NPV is 69,608.75×10^9 USD.

6.1.3.2. Tiefa Prospect of Northeast China

Tiefa prospect is located in Tiefa City and is of the North Temperate Zone subhumid monsoon continental climate with much rain in summer, abundant sunshine, gale in spring and a long cold winter. The transportation here is convenient, with developed railways and highways. The underground CBM extraction carried out by Tiefa Coal Group Industry is being commercially developed.

The geographical position of the Tiefa prospect is favorable and the local Tieling and Tiefa City have a strong demand for the CBM, so the CBM market is very good.

In the economic evaluation of Tiefa prospect, when the single-well productivity in the stable production period is 2,506 m^3/d, sold to Tieling and Tiefa, the development financial NPV is 60,546.54×10^3 USD.

6.1.3.3. Fuxin Prospect of Northeast China

The Fuxin prospect is located in the Fuxin basin of Liaoning Province and is between Shenyang and Jinzhou. The prospect is temperate continental monsoon climate and has sufficient sunshine, four distinct seasons and appropriate temperature. The prospect has convenient transportation conditions and several first-class highways. Fuxin is connected to Shenyang and Jinzhou by the Fuxin-Shenyang and Fuxin-Jinzhou highways. The CBM exploration activities started earlier in Fuxin prospect and presently the Fuxin Coal Group have started the CBM commercial production by underground extraction and small-scaled surface extraction.

Fuxin city has a strong demand for the clean energy and the government has made a CBM utilization plan for local residents and industry. If the plan is put into practice completely, all the CBM of Fuxin prospect will be consumed locally.

In the economic evaluation of Fuxin prospect, when the single-well Productivity in the stable production period is 2,619 m^3/d, and the CBM is expected to be sold in Fuxin City, the development financial NPV is 59,968.47×10^3 USD.

6.1.3.4. Hongyang Prospect of Northeast China

The position of the Hongyang prospect is 20km away from the Shenyang City in the south and the prospect belongs to the mountainous and hilly area. It is temperature subhumid continental climate and has sufficient rain, gretat varation in temperature, and four distinct seasons. The Shenyang is the traffic center of Northeast China and the roads and railways are very developed.

In Hongyang prospect, CBM has not been commercially produced, but the big cities like Shenyang have a dense population, developed economy, a strong demand for clean energy and great market potential.

In the economic evaluation of Hongyang prospect, when the single-well productivity in the stable production period is 2048m^3/d,and the CBM is expected to be sold to Shenyang and Liaoyang, the development financial NPV is 51,670.71×10^3 USD.

6.1.3.5. Hegang Prospect of Northeast China

Hegang prospect is located in Hegang City of Heilongjiang Province or the transitional area between Lesser Khingan and Sanjiang plain and it is separated from the Russia by Heilongjiang River in the north, near the Songhua River and next to Jiamusi in the southeast. In the west, the prospect is besides Lesser Khingan and neighbour to Yichun. The prospect has temperate continental monsoon climate and has abundant sunshine, four distinct seasons and preference temperature. The transportation is convenient in the prospect and the Hegang-Yichun, Hegang-Jiamusi, Hegang-Luobei highways connects the Hegang city to the around cities. Besides, the CBM can be transported to Haerbin, Dalian etc by railways. Presently the Juyuan CBM Limited Liability Company of Hegang Coal Group and the Hegang Filiale of Heilongjiang Coal Group is carrying out commercial utilization activities of underground CBM extraction.

The market condition of the CBM development in Hegang prospect is favorable and both Hegang and Jiamusi have a great demand potential for the CBM.

In the economic evaluation of Hegang prospect, when the single-well productivity in the stable production period is 1929m^3/d, and the market is expected to be in Hegang and Jiamusi, the development financial NPV is 46,497.81×10^3 USD.

6.1.3.6. Shuangyashan Prospect of Northeast China

Shuangyashan prospect is located in Shuangyashan city of Anbang riverside in north Wanda mountain range in northeast Heilongjiang. The prospect is located in the middle-high latitude and is of cold temperate zone continental monsoon climate with a long, cold and dry winter and short, mull and rainiess summer. The transportation of the CBM is easy and the railways and roads have been constructed in the prospect.

The market condition of the CBM development in Shuangyashan prospect is favorable and the Jiamusi of Shuangyashan in which the prospect located has a great demand potential for the CBM.

In the economic evaluation of Shuangyashan prospect, when the single-well productivity in the stable production period is 1936m^3/d, and the market is expected to be in Shuangyashan and Jiamusi, the development financial NPV is 44,534.56×10^3 USD.

Jiamusi is one of the potential markets of Hegang prospective, and in the integrated ranking, Shuangyashan is lower than Hegang. Since Hegang occupies the market of Jiamusi, the economic benefits of the development of Shuangyashan will be lower than the economic evaluation results of this research. Therefore, on the basis of making full use of Shuangyashan market, new markets should be explored actively to improve the economic benefits.

6.1.4. The Favorable CBM Prospects of Central China

6.1.4.1. Lianshao Prospect of Central China

Lianshao prospect is located in the middle of Hunan Province and belongs to semi-hilly and semi-upland topography. It is subtropical continental monsoon climate with sufficient sunshine, preference temperature, four distinct seasons, and few scorching days in summer and few freezing days in winter. The transportation is very convenient in The Lianshao prospect, with easy access to Xiangqian railway, 207 and 320 national highways.

Lianshao prospect has a dense population and developed economy. The CBM can be supplied to some big and medium-sized cities such as Changsha, Loudi, Shaoyang etc, so it has a big CBM market potential.

In the economic evaluation of Lianshao prospect, when the single-well productivity in the stable production period is 1957m^3/d, and the CBM is expected to be sold to Loudi, Shaoyang and Changsha, the development financial NPV is 150,612.6×10^3 USD.

6.1.4.2. Fengcheng Prospect of Central China

Fengcheng prospect is located in the Fengcheng City of the Poyang basin in the middle and lower stream of Ganjiang River and belongs to downy and plain topography. The climate is subtropical moist climate with four distinct seasons, warm climate, abundant rainfall and sunshine. CBM here can be easily transported to other places from the region.

Fengcheng prospect has not been commercially produced, but Fengcheng City and the around Nanchang, Xinyu, Yichun City has a dense population and developed economy. So it has a strong demand for the clean energy and a great market potential.

In the economic evaluation of Fengcheng prospect, when the single-well productivity in the stable production period is 2154m^3/d, and the market is Fengcheng, Nanchang, Xinyu and Yichun, the development financial NPV is 79,449.56×10^3 USD.

6.1.5. The Favorable CBM Prospects of Southwest China

6.1.5.1. Baiyanghe Prospect of Northwest China

Baiyanghe prospect is located in the northeast of Urumqi and is between the Urumqi and Baiyanghe. The prospect is in a foothill area, and the topography is high in the south and low in the north, high in the east and low in the west. In the prospect, from west to east, there are Urumqi River, Shuimo ditch, Tiechang ditch and Baiyang River etc. The discharge of stream of these rivers is not generous, but in the thaw period of spring and rainstorm period of summer there will be floods. The prospect has emperate monsoon dry climate with short springs and autumns, long winters and summers, great temperature variation between days and nights, and little rainfall. The transportation is very convenient in the prospect which is crossed by Lanzhou-Xinjing railway in the west and the highways are very developed in the centre of the Urumqi [1]. Presently, the CNPC is carrying out exploration in the prospect.

The economy of the Xinjiang area is comparatively less developed but coal, oil and natural gas resources are rich, and the local demand for CBM is limited. But the prospect is near west-east transportation pipelines and its CBM can replace gas supply, and the prospect has good transportation condition.

In the economic evaluation of Baiyanghe prospect, when the single-well productivity in the stable production period is 2028m^3/d, and the CBM is transported to the east via West-East transportation natural gas pipeline, the development financial NPV is 42,709×10^3 USD.

6.1.5.2. Enhong Prospect of Southwest China

Enhong prospect is located in the Qilin region and Fuyuan County of Qujing City of the Yunnan Province which is in a plateau mountain area. The climate here is subtropic monsoon climate, so the summer is not very hot, the winter is not very cold and the dry and wet seasons are distinct. But sometimes there is some disastrous weather such as the drought, flood, hailstone, frost, cold damage, tornado and so on. The prospect has convenient transportation and is connected to the near cities and counties by roads. In 2002, the China CBM and Far East Energy Company of the United States jointly started to carry out exploration activities in the prospect.

Presently, the energy of Yunnan Province has mainly coal and water power resources with little oil resources and oil consumed here comes from other Provinces, and therefore there is a strong demand for the clean energy [4]. The Enhong prospect is near the Kunming, Yuxi, Qujing and has a dense population and developed economy. It is also the economy and consumption centre and the CBM demand potential is very great [5].

In the economic evaluation of Enhong prospect, when the single-well productivity in the stable production period is 2059m^3/d, and is expected to be sold to Kunming, Qujing and Liupanshui, the development financial NPV is 21,449.62×10^3 USD.

In the favorable CBM prospective described above, Xianxia, Hongyang, Baiyanghe and Xinglong have made full use of their CBM resources in the evaluation period, while the other prospectives will have a considerable amount of CBM resources when the evaluated period ends, especially in oversized target areas such as Yangquan, Jincheng and Hancheng, where remaining CBM resources are still enormous after the evaluated period. Therefor, in the development of these favorable target areas, markets should be actively expanded in order to achieve greater economic benefits.

6.2. The Advices of the CBM Pilot Test

When selecting the pilot test prospect in the favorable prospect, we should follow these principles: the favorable prospect has not carried out CBM pilot; the favorable prospect has carried out CBM exploration and evaluation activities and has the condition to carry out pilot tests; the favorable prospect has potencial market. According to the comprehensive analysis, we think the Hancheng prospect is a favorable position where we can carry out the CBM pilot test and if the pilot test succeeds, it will encourage and accelerate CBM development and utilization.

6.2.1. The Basic Conditions of Carrying Out CBM Pilot Test in Hancheng Prospect

Hancheng prospect is one of the areas where CBM exploration activites started earlier and many enterprises and research institutions have been carrying out exploration and evaluation activities to the Hancheng prospect since the 1980s. Through much prophase work, some geological parameters (geological characteristic, coal reservoir characteristic etc.) have been defined primitively and some CBM enterprises have got the CBM proved reserves. Besides, the market condition in Hancheng prospect is better and completely meets the need of small-scale CBM sale. The prophase work and favorable market condition provide a stable base for carrying out CBM pilot test in the Hancheng prospect.

6.2.2. The Conceptual Design of the Pilot Test Plan in Hancheng Prospect

In the conceptual design of the pilot test, the pilot test plan is made based on the CBM geological characteristics, coal reservoir characteristics, existing technology conditions of China and the market conditions of Hancheng prospect.

6.2.2.1. Development of the Target Horizon

In Hancheng area there are three main recoverable seams (Coal Number 3 of Shanxi group, Number 5 and 11 of Taiyuan group) which are also the main target coal seams of the CBM development. The burial depth of the coal seams is 300 m~900 m and the intervals of coal seams is 20 m~40 m.

6.2.2.2. Drilling Engineering Plan

1) Drilling style

Presently, the existing drilling styles of the CBM activities in China are vertical wells, cluster wells and horizontal wells. According to the CBM geological condition of the prospect and the economical efficiency of different drilling styles, we think the vertical well is the most practical in the CBM pilot testes of the prospect.

2) Drilling technology

According to the applicability and mature degree of the present CBM drilling technology in China and the CBM geological condition of the prospect, we think the rinsing drilling is the first selection and the air drilling is the second selection in ground vertical drilling; cementing well with low-density grout; increasing production mainly depends on the hydraulic fracture and nitrogen foam fracture.

3) Developing well network

The geological structure of the area is simple with gentle physiognomy, low burial depth and stable CBM and low mountains and hills are the main parts of the prospect. Drawing lessons from the CBM development experiences of Qinshui basin, we think the rectangle network is practical in the CBM pilot testes of the prospect.

6.2.2.3. The Plan for Surface Work

1) The surface gathering and transportation

According to the CBM well characteristics of small space interval, low single well production and low wellhead pressure, the CBM gathering and transportation mainly applys following techniques: gathering gas with low pressure, simple single well measurement, single pipe concatenation of multiwell and centralized dehydration treatment. Meanwhile, we adopt the technological process of 'wellhead- production pipeline- gas gathering station- centralized treatment plant.' First, the CBM is transported via production pipelines and by self pressure to the gathering station where we will carry out some treatments such as separation and pressure increase etc. Then the CBM is transported by gathering piplines from the wellhead to centralized treatment plant where we will carry out drastic dehydration and pressure increase and so on and finally we will provide standard CBM for the out transportation.

2) Out transportation

Presently, Hancheng prospect has notlocal transportation pipelines and branch pipelines which are connected to the West-east Transportation Pipeline, so the out transportation mainly depends on tankers. According to the eleventh Five-year Plan of the CBM development and utilization, if the CBM pilot testes of the prospect are successful, the Chinese government may support the construction of the long and special Hancheng-Houma-Linfen pipeline of which the capacity is 500×10^3 m^3.

6.2.2.4. Development Time

According to the results of numerical simulation, and considering the actual situation of the gas content, gas saturation, and seam thickness in this area, we define that the production period of the single CBM well in this area is fifteen years. According to different pilot tracey scales, construction period can be designed as one year or two years; with no consideration of the situation of replacing, the production period is 15 years, therefore the whole pilot test cycle is sixteen or seventeen years.

6.2.3. Investment and Cost Estimation of the CBM Pilot Test in Hancheng

The scale of the CBM pilot test and the optimization of ground technology etc can influence the investments and costs, however, because of the few Chinese successful CBM exploitation and production activities, we can not quantify the impacts of the above factors on the investment and cost, we do not consider the impacts of these factors temporarily.

6.2.3.1. Investment Estimation

Based on the study of the basic exploitation data in Qinshui CBM basin, the investment per unit of ground vertical drilling well in this area is about 219.0×10^3 USD, and the investment per unit of first surface work is about 1.2782×10^3 USD/km^2. And the other investments (including flow capital) can be estimated as 6% of fixed assets. When the scale of the CBM pilot tests are

100 wells and constructing by all of its own funds, the total construction investments are about 36.71×10^3 USD。

6.2.3.2. Cost Estimation

Based on the study of the basic exploitation datas in QinShui CBM basin, the operation costs per unit of CBM exploitation is about 0.049 USD/m^3 in this area.

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Chapter 7 CBM Activities and Industry development in China

As energy security and environmental protection have become the important issue, Chinese CBM industry has entered the period of rapid development. Many domestic and foreign companies that joined China CBM exploration and development have not only got breakthroughs in CBM commercial production, but also accumulated valuable experiences in CBM development and utilization. At present, Chinese CBM industry is in the substencially significant period of large-scaled commercial development, so it urgently needs the government to make effective policies and laws to guide its healthy development.

7.1. Chinese CBM Enterprises

7.1.1. Important CBM Enterprises in China

7.1.1.1. China National Petroleum Corporation

1) Brief introduction

China National Petroleum Corporation (CNPC) is an integrated energy company. As the largest energy provider in China, its business includes oil-gas exploration and development, oil refining and chemical engineering, gas stations, oil–gas storage and transportation, oil trade, engineering and technical services and oil equipment manufacturing. In 1994, CNPC set up the Department of CBM Project Management, starting CBM resource exploration work in China. CNPC has license to develop a number of CBM blocks, covering more than half of the total Chinese CBM resources, and has already developed relevant technology for the CBM exploration and development.

2) Progress of CBM exploration and exploitation

By the end of 2006, CNPC Department of CBM Project Management had drilled in 15 blocks of 7 coal-beaing basins, including Ordos, Tuha, Qinshui, Ningwu, Jizhong, Lengshuijiang in Hunan, and Fengcheng in Jiangxi, with more than 200 wells drilled, completed two-dimensional seismic exploration of over 400 km, and invested over $75.95×10^6$ USD. Up to September 2007, CNPC had achieved many important exploration results as follows [1,3,4]:

a. Exploration results in southern Qinshui Basin

At Zhengzhuang Block in southern Qinshui Basin, CNPC has got proved reserves of $46×10^9$ m^3 and control reserves of $80.4×10^9$ m^3. It is expected that the reserves would add up to $100×10^9$ m^3 after further detailed exploration.

b. Exploration results in the east of Ordos Basin

In Daning-Jixian region in the east of Ordos Basin, CNPC had got control reserves of $79×10^9$ m^3. It is expected that the reserves would be $100×10^9$ m^3 after further exploration.

Moreover, CNPC has made great progress in the southeast edge of the Junger Basin and the southern Ningwu Basin.

3) Strategies and plans for CBM development

In the “11^{th} Five-Year Plan” period, CBM activities of CNPC are turning from exploration to development. It is expected that the production ability would be $3×10^9$ m^3 in 2010. To achieve this goal, CNPC will increase investment in the research on the basic theory and key technology of CBM; According to the characteristics and distribution of China CBM resources, it will select favorable and representative blocks as key areas for the exploration and development, construct some demonstration projects just as high-rank coal in Qinshui Basin, medium-rank coal of Daning-Hancheng in the Ordos Basin and low-rank coal in the southeast of the Junger Basin, which would spur the development of local CBM; CBM pipeline construction will be incorporated into the overall business plan, and construction of infrastructure will be strengthened [2,4].

4) Analysis of market competition ability

With rich CBM reserves, great technical capabilities and investment of many years, CNPC becomes one of the leaders of the CBM industry in China. As gradual shift of the CBM industry to large-scale development, operation right of gas pipelines is the most important competitive advantage. CNPC has the operation right of the West-to-East Gas Transmission Pipeline and the Shanjing Pipeline. The two pipelines pass many CBM rich areas, providing favorable transportation condition for the CBM large-scale development of CNPC. Moreover, CNPC is a prestigious comapny and vast profitability, which provide favorable conditions for its future international cooperation and ability to input huge investment in CBM.

7.1.1.2. China United Coalbed Methane Corporation Limited

1) Brief introduction

China United Coalbed Methane Corporation Limited (China CBM) is organized in March 1996 by the approval of the State Council and is the most important CBM enterprise in China and enjoys the exclusive right for external cooperation in CBM exploitation in China. Its main duties are CBM exploration, development, transportation, marketing and utilization as well as tender, negotiation, agreement signing and agreement implementation, which are approved by the State Council.

2) The progress of CBM exploration and development

China CBM has started a number of exploration and pilot tests operated by themselves or through joint ventures, and made great progress in exploration and development, main achievements:

a. Progress in the southern Qinshui Basin. Panzhuang and Shizhuangnan blocks in the south of Qinshui Basin, where the exploration level is very high, both have obtained proved CBM geological reserves approved by the State, and have the conditions for large-scaled development. At present, the two blocks have set up small-scale development projects, and started commercial production and distribution.

b. Progress in Ordos Basin. In Hancheng area of the Ordos Basin, China CBM has discovered and proved a CBM field with proved geological reserves of 5×10^9 m^3, including recoverable technical reserves of 2.505×10^9 m^3, and economical recoverable reserves is 2.255×10^9 m^3. The Hancheng CBM field is another important discovery after the Qinshui Basin [5].

3) CBM development strategy and plan

China CBM has made a plan for CBM surface extraction and put forward strategic goal, taking its advantages in CBM resources, market and policy.

a. Planned area and project arrangement. Focusing on Huabei area, choosing the southern Qinshui Basin CBM project and Hancheng Shaanxi project as starting points, China CBM carries out systemic feasibility evaluation research, imployed unilinear exploration and development deployment and constructed CBM commercial production bases step by step. For the continuity of the CBM exploration and development, while implementing and constructing demonstration projects else where, the CBM exploration in Yunnan, Heilongjiang, Liaoning, Inner Mongolia, Anhui, Jiangxi is continued and the discovered reserves will be submitted according to the plan.

b. Planned block for CBM surface production. The planned objectives of China CBM for CBM surface production are: to complete CBM trial projects within 3~5 years from 2004 with production ability exceeding 1.0×10^9 m^3~1.5×10^9 m^3 by 2015, to build 3~5 CBM production bases with annual production ability exceeding 5×10^9 m^3~10×10^9 m^3, to obtain production ability exceeding 20×10^9 m^3 by 2020 [6].

4) Analysis of market competitive power

China CBM is one of the leaders in Chinese CBM industry. Its most important competitive stength is its exclusive right for external cooperation in CBM exploration, development and production. Up to the end of 2006, China CBM had signed 27 CBM production-sharing contracts with 16 foreign corporations. Through cooperation with foreign corporations, China CBM has introduced a number of foreign funds, advanced technology and international management experiences into their CBM activities. Only in 2006, China CBM had attracted a total foreign investment of 71.24×10^6 USD, which relieves the strain of capital shortage to a large content.

7.1.1.3. China Petroleum & Chemical Corporation

1) Brief introduction

China Petroleum & Chemical Corporation (Sinopec) is an oversize oil and petrochemical group, and is the second biggest energy provider. Its business includes industrial investment and investment management; oil and gas exploration, exploitation, storage and transportation (including pipeline transport), marketing and comprehensive utilization; oil refining; gasoline, kerosene, diesel oil wholesale; production, gas station, storage and transportation of petrochemical and other chemical products; petrochemical projects exploration design, construction and installation; petroleum and petrochemical equipment overhaul maintenance; electrical equipment manufacturing; technology and information and research, development, application, business consultant services of alternative energy production. There is very rich CBM resource in licensed blocks of Sinopec Group, which is distributed in the four biggest coal-bearing areas like Northwest, Huabei, South and Dongbei, covering a total area of $989×10^6$ km^2 and total CBM resource of $11.26×10^{12}$ m^3 [1].

2) Progress of CBM prospects selection

Through resource evaluation to coal-bearing blocks with prospecting right, Sinopec Group confirmed 9 main CBM exploration areas, namely: Huainan block, Huaidong block and Huaibei block in the Junger Basin, Yining block in the Tianshan Basin, Hami block in the Tuha Basin, Hangjinqi block, Yanchuannan block in the Ordos Basin, Heshun block in the Qinshui Basin, and Tongzi-Anshun block in the Chuannan-Qianbei. Among those, Yanchuannan block in the Ordos Basin and Heshun block in the Qinshui Basin have total CBM resources of about $182.4×10^9$ m^3, with expected proved reserve of $100×10^9$ m^3. At present, technology for the two blocks has been basically full-fledged. They would become the important objectives of Sinopec Group to increases production and get production breakthrough recently [1].

3) CBM development strategy and plan

The scale of the Sinopec Group CBM activities is much smaller. CBM exploration and development is one of the strategies of Sinopec Group. Currently, in aspect of the selection of CBM blocks, some experts have put forward the suggestion about CBM development strategy for Sinopec Group.

a. Accelerating the growth of CBM reserves in Sinopec Group. From non-registered and cancelled blocks of China, Sinopec should register the blocks with favorable geological conditions. After getting perspecting right, it should implement thorough evaluation and careful selection of the CBM prospects and reserve favorable blocks. For the registered conventional oil-gas exploration blocks, it should implement general comprehensive exploration in the areas with favorable CBM geological conditions, so as to reduce costs and shorten evaluation time.

b. Increasing investment in CBM exploration and development. Through increasing investment, the exploration evaluation, technical innovation as well as equipment upgrading and reformation will be accelerated.

c. Setting up special CBM management organization. It should set up special organization to coordinate scientific research and engineering teams and absorb talents, in order to concentrate on promoting its development of CBM business.

4) Analysis of market competitive power

In recent years, the investment is very limited in the CBM exploration and development and the scale is also small, but Sinopec Group still has strong market competitive power in CBM. CBM reserves of Sinopec Group are quite large with wide distribution scope. Some significant exploration areas have favorable geological conditions, which provides abundant material base for the CBM business development. Sinopec Group started CBM business earlier. So it has formed a complete set of technology series for the CBM exploration and development and has a group of CBM-related professionals [1]. Moreover, the wellknown name and financial strength of Sinopec Group are also the important foundation for the CBM business development.

7.1.1.4. Jincheng Coal Group

1) Brief introduction

Located in the east of Jincheng mining area, Jincheng Coal Group is one of the confirmed national top 520 key enterprises. The corporation has four production mines and one trial production mine, namely, Gushuyuan Mine, Wangtaipu Mine, Fenghuangshan Mine, Chengzhuang Mine and Sihe Mine. The designed production capacity is $17.1×10^6$ t. As an important anthracite production base in China, the corporation possesses international standard advanced mining equipment and modern selecting and processing system with strong technical expertise and advanced administration.

2) Progress of CBM block selection

In 1992, for the purpose of coal mine production safety, Jincheng Coal Group started to engage CBM ground pre-trial test. After production test and technology research of more than 10 years, Jincheng Coal Group has basically mastered a whole set of surface extraction technology aimed at anthracite, such as the technology for CBM drilling, fracturing, draining and gathering and transportation. In 2003, Jincheng Coal Group began large-scaled CBM surface extraction. Currently, well groups containing 600 CBM wells have formed in Panzhuang, Chengzhuang, Zhengzhuang area of Qinshui Basin. Along with the increase of CBM well putting into production, CBM output is continuously increasing. At present, the daily production rate is already 500×10^3 m^3 [1,2].

Jincheng Coal Group has also set up a relative perfect system of CBM utilization. Its CBM in Panzhuang region has been compressed and transported to surrounding cities, and is widely used in civil, industry, power generation and fuel for vehicles. At present, the exported CBM of Jincheng Coal Group has already reached 290×10^3 m^3~380×10^3 m^3. With the completion of new CBM compressions and transportation pipeline, the utilization rate and exported amount by Jincheng Coal Group, drilling CBM well activity will still increase.

3) CBM development strategy and plan

In the "11th Five-Year Plan" period, Jincheng Coal Group will continue to carry out large-scale surface CBM pretrial aiming at production mines and waiting production mines. It is estimated that, at the end of "11th Five-Year Plan", surface drilling wells will be 2000, and the annual CBM production will be 1.8×10^9 m^3 (including underground production) [2].

4) Analysis of market competitive power

As a regional coal corporation, Jincheng Coal Group has relatively strong competitive power in CBM exploration and development of Shanxi Province. Jincheng Coal Group owns perfect CBM resources in the coal production area. According to *Notice about strengthening the Management of Coal and CBM Resources Exploration and Development* published by The Ministry of Land and Resources P.R.C, as one of the 13 large-scaled coal bases planned by Chinese government, in its coal licensed area, Jincheng Coal Group could get support from the government in aspect of CBM exploration right. Moreover, Jincheng Coal Group has basically mature CBM surface drainage technology adapting to local coal seam geological condition, and the CBM utilization system has elementally set up, which create favorable conditions for the industrialization operation of CBM.

7.1.2. Main Foreign CBM Enterprises Operating in China

Foreign energy corporations have increased investment in and competition for CBM exploitation in China. Up to June, 2007, about eighteen corporations from The United States, Canada, Britain, Australia etc. have engaged in the CBM exploitation in China. These foreign corporations include Chevron, Far East Energy Corporation, Reflection Oil & Gas Partners, Ltd, Verona Development Corporation, TerraWest Energy Corp and to name only a few.

7.1.2.1. Chevron

Chevron is a famous global interinational energy company, and its activities cover more than 180 countries and regions in the world. The company traces its earliest roots to an 1879 oil discovery at Pico Canyon, north of Los Angeles, a discovery that led to the formation of the Pacific Coast Oil Co., which later evolved into the Standard Oil Co. of California and, later, Chevron Corp. Another major root in the genealogical chart is the 1901 formation of The Texas Fuel Co. in Beaumont, Texas. It later became known as The Texas Co. and, eventually, Texaco Inc. In 2001, these entities merged to form Chevron Texaco. The name was changed to Chevron in 2005 to present a more unified presence in the global market. The acquisition of Unocal Corporation in 2005 strengthened Chevron's position as a global energy leader and enhanced its assets in key basins around the world.

In January, 1998, the Texas Co. (unite with Chevron later) became the first foreign company signing a contract with China United Coalbed Methane Corporation Limited to explore and produce CBM in China. Later, the Chevron gained six joint projects, which are Sanjiao, Sanjiaobei, Linxing, Zhungeer, Baode and Shenfu and explorated actively in the six contract blocks [8].

7.1.2.2. Far East Energy Corporation

Far East Energy began operations on 31st December, 2001. The company's early efforts focused on the evaluation of domestic and global opportunities to develop natural gas and CBM properties. Upon the completion of substantial examination and due diligence for CBM opportunities, FEEC entered into two Product Sharing Contracts with China United Coalbed Methane Corporation, Ltd. (CUCBM) on 25th January, 2002. FEEC and CUCBM will jointly explore, develop, produce and sell CBM in a total area of 1,073 km^2 in Enhong and Laochang areas of Yunnan Province, P.R.C. It is estimated by the Yunnan Provincial Coal Geological Bureau that the joint venture area contains total gas-in-place in excess of 150×10^6 m^3 of methane.

On 17th June 2003, Far east acquired its preeminent holding, obtaining two farmout agreements from ConocoPhillips, covering over 1.0×10^6 acres in the Shanxi Province of Northern China. This could prove to be the world's largest CBM project. Based on the estimates by ConocoPhillips and Yunnan Provincial Coal Geology Bureau, Far East's entire project areas in China combined potentially contains 518×10^6 m^3~705×10^6 m^3 of total gas-in-place. If a recovery rate is assumed to be 50%, recoverable CBM resources are potentially 260×10^6 m^3~354×10^6 m^3 [9].

7.1.2.3. Asian America Coal Inc. (AACI)

Asian American Coal Inc. (AACI) was formed by a number of U.S. coal mining companies and financial institutions for the purpose of investing in coal production, preparation, coal sales, and CBM projects in China. AACI's shareholding companies have investments in energy-related projects in the United States and around the world. These investments include coal and natural gas production as well as electric power generation. Both the individual investors and company investors of the corporation have combined experiences of over 250 years in mining industry with a great deal of annual production.

Since 1994, AACI and its main shareholding companies have invested over 50×10^6 USD in coal mining and CBM projects in Shanxi Province, China. In 16th July, 2004, AACI and CUCBM signed one Product Sharing Contract to jointly develop the Mabi block CBM resources of Shanxi Province [10].

7.1.2.4. Pacific Asia China Energy Inc. (PACE)

PACE is the first Canadian company to explore and develop CBM resources in China. Its entry into the Chinese market follows the United States corporations such as Chevron-Texaco, ConocoPhillips and Far East Energy Corporation which have begun exploration in recent ten years. PACE is a holding company that recently acquired 100 percent of Asia Canada Energy Corp and China Canada Energy Corporation (CCE). In 20th September, 2005, Asia Canada Energy Corporation and China CBM signed a Product Sharing Contract to jointly develop the CBM resources of Qingshan block in Baotian of Guizhou. The contract area is about 947 $km^{2,}$ and predicted CBM resources are about 160×10^9 m^3. In the four-year exploration period, Asia Canada Energy Corporation would take all exploration risk and adopt advanced technology to verify the CBM in contract area. In development and production period, both sides invest together and then divide deserved CBM production according to the investment proportion. In October, 2003, China Canada Energy Corporation and China CBM subscribed a CBM exploitation and Product Sharing Contract of Huangshi area, in which the foreign side would invest to carry out risk exploration. The period of the contract was thirty years, including an exploration period of two years [11].

7.1.2.5. TerraWest Energy Corp.

TerraWest Energy Corp. is established to develop the china's CBM resources, whose controlling shareholder is Norwest Corporation. Norwest Corporation was founded in 1979, and its main business was to provide services of consultation and engineering services in energy, mining and nature resources. Its activities cover the whole world and possess offices in the United States, Canada, Australia, India, and Indonesia and so on. In May, 2004, Norwest Corporation set up an office in china, which provides technical services for energy and mineral companies especially in gold, coal, cooper, oil sand and CBM areas. The HQ of TWE was erected in Calgary and helped companies of China to seek CBM resources. In 30th December, 2005, the TWE and China CBM signed the contract of exploring for the CBM of Liuhuang block in Xinjiang [12].

7.1.2.6. Reflection Oil & Gas Partners Ltd (Reflection)

Reflection Oil & Gas Partners Ltd (Reflection) is an international energy corporation specialized in the gas and CBM development, whose HQ is in London of British. In February, 22, 2006, Reflection and China CBM signed the contract of developing the CBM of Shilou south block in Luliang of Shanxi. The contract let Reflection take the management risk and invest at least 6.3291×10^6 USD during exploration period beginning in the mid of 2006. China CBM will put 40% investment in the development and production period, and the Reflection will invest the other 60% [13].

7.1.2.7. Greka Energy Corporation

Greka is an upstream gas energy production company. Greka is specialized in the CBM development in China and it is one of the biggest CBM development corporations. Greka and China CBM have signed CBM exploration and development product sharing contract of five blocks, of which three blocks, suh as Shizhuangnan, Shizhuangbei and Qinyuan, are located in the Qinshui Basin of Shanxi, and the other two are located in Jiangxi Province (Fengcheng block) and Anhui Province (Panxiedong block) [14].

7.2. Activities of CBM Exploration and Development in China

7.2.1. Ground Exploration and Development

The CBM Ground development began on the late 1970s and the Fushun Research Institute of Central Coal Mining Research Institute, aiming at solving the problem of coal mine gas, and drilled more than twenty surface extraction test wells in Fushun, Yangquan, Jiaozuo, Baisha, Baotou and so on. But, because of the limitation to well locations, technology and equipment, the tests did not reach the anticipated goal. To the 1990s, with assistance of American technology, CBM surface development activities experienced an upsurge and many CBM development tests were carried out in different areas. Over more than ten years of tests, the CBM surface development in china has acquired great progress.

According to the data of the Second China CBM Academic Symposium in 2007, China had drilled 1,843 vertical wells, 25 multi-branched horizantal wells, and 479 production wells. The daily gas output had been over 1.15×10^6 m^3 [1] (Table 7.1). Chinese CBM exploration and development activities can be classified to those operated by domestic companies and by joint ventres. At present, the acquired important progresses include:

a. CBM exploration. After Qinshui CBM field in Shanxi, a new CBM field with proved geological reserve of 5×10^9 m^3 has been found in Hancheng Shaanxi Province.

b. Small-scaled CBM commercial development [2,16]. Qinshui Basin in Shanxi is the most concentrated area for CBM activities in recent years. Small-scaled commercial development of CBM also concentrates here. The representative projects are Zaoyuan Qinshui well group CBM development test project, Panzhuang Jincheng CBM surface development project, Panhe Qinnan pre-test project and Sihe Mine Jincheng Coal Group CBM surface pre-drainage project. Moreover, the CBM development project of Liujia well group in Liujia region, Fuxin, Liaoning Province, started small-scale commercial sale in 2003.

3) The application of multi-branch horizontal drilling technology [1,2]. Multi-branch horizontal drilling technology is very important for the effective exploitation of CBM, especially for improving the effect of the surface CBM pre-extraction of the coal mines. In December 2004, at Daning, Shanxi coal mine, the first multi-branch horizontal well project for the CBM development in China was implemented successfully. At present, China has 25 multi-branch horizontal wells, 6 in Daning, 11 in Duanshi, 3 in Shouyang, 3 in Fanzhuang, 1 in Ningwu and 1 in Wucheng.

7.2.1.1. Domestic Self-Supported Projects

Table 7.1 shows that the main domestic enterprises with comparatively larger scale of the ground CBM development are CNPC, China CBM, Jincheng Coal Group, Fuxin Mine Group and so on. The successful domestic self-supported projects are also operated by the four companies.

Table 7.1 Situation of Chinese CBM drilling

Organization	Vertical well	Horizontal well	Percentage, %
PetroChina	580	5	31.32
China United Coalbed Methane Co. Ltd.	372	5	20.18
Sinopec	15		0.8
Jin Coal Group	700		37.47
Fuxin Mine Group and Liaohe Petroleum Exploration Bureau	32		1.71
SinoCoal Geology Bureau	25		1.34
Greka	24		1.28
Asian-American, Sino-American Energy		12	0.64
UNDP	12		0.64
Others	83	3	4.60
Total	1,843	25	100

Source: Zhao Qingbo, 2007.

a. Shanxi Qinnan Panzhuang CBM development project of CNPC. Up to the end of 2006, the project had drilled 200 wells. It plans to set up a CBM production base which will produce CBM of 2×10^9 m^3 by the end of "11th Five-Year Plan".

b. Shanxi Qinshui Zaoyuan CBM pilot test project of China CBM [2]. The project has set up 15 CBM production test wells, a small-scale CNG compression station with compression ability of 36×10^3 m^3 and a small-scaled CBM power plant with daily power generation of 400 KW. In April 2003, the project began to supply gas to market.

c. Shanxi Panhe advanced technology industrialization model project of China CBM [16]. According to the plan, 900 CBM production test wells will be drilled at three different stages. At the first stage, it had drilled 150 wells and built up a CBM production trial base with annual production capacity of 100×10^6 m^3 through an investment of 46.08×10^6 USD. The produced CBM of 30×10^6 m^3 will be transported by compressor bus to Jincheng, Changzhi of Shanxi and Linzhou of Henan for residential use; the other 70×10^6 m^3 will be transported through main gas line to Linfen, Yuncheng and other places for industry use. At the second stage, 400 CBM production test wells are planned to be drilled, and the production will be increased by 300×10^6 m^3 per year reaching 400×10^6 m^3 per year. At the third stage, 350 CBM production test wells will be drilled, and the production will rise by 300×10^6 m^3 per year with total production of 700×10^6 m^3 per year.

d. Shanxi Duanshi multi-branch horizontal well project of China CBM [2]. The project is one of the national strategical prospect selection project for oil and gas. The aims of this project are to apply the multi-branch horizontal drilling technology in the CBM development as well as to relieve the methane danger in high-methane-content coal mines. The project began in 2005 and will be finished up in 2008 and the target is located in the Qinshui Bason of Shanxi Province. Five multi-branch horizontal wells are planned to be drilled, adding up to seventeen single horizontal wells, and then a CBM production base with capacity of 100×10^6 m^3 will be built up.

e. Sihe Mine CBM surface pre-extraction project of Jincheng Coal Group [2]. The project started in 2003. By the end of 2005, 150 wells had been drilled with annual production ability of 120×10^6 m^3. The project has set up comparatively complete gathering pipeline network, gas-collecting stations and compression stations. Currently, the project supply CBM to Jincheng, Changzhi, Taiyuan, Zhengzhou, Jiaozuo, Kaifeng, as well as rural residents around the mining area.

f. CBM development and utilization project of Fuxin Mine Group. The project started in 1992.

By June, 1997, the first-stage construction finished. In the second half of 1998, the second-stage construction that use CBM instead of coal gas started in order to make the urban residents enable to use safe, harmless and clean energy. In March 2003, Fuxin Coal Gas Company began to supply CBM to 70,000 urban residents. During one year, the highest daily amount of supply would reach 170×10^3 m^3 in one year. The third stage started in 2003 with daily supply capacity of 216.4×10^3 m^3.

7.2.1.2. Foreign Cooperative Project

As early as in the 1990s, some foreign companies had come to China to invest in the CBM exploration and development. Up to June 2007, China United Coalbed Methane Co. Ltd had signed 28 product-sharing contracts on CBM exploration with 18 foreign companies. Cooperation blocks extended to 10 Provinces such as Shanxi, Shaanxi, Inner Mongolia, Xinjiang, Guizhou, Yunnan, Jiangxi, Anhui, Hubei and Ningxia (See Table 7.2). With the incentive force of commercial production trial projects, foreign investments increased dramatically. In 2006, the investment was 76 million USD and 120 million USD in the first half of 2007. Through the development of above-mentioned cooperative projects, the company acquired large amount of geological information about CBM projects, and basically clarified the resources conditions in the blocks. Meanwhile, through cooperation, the company introduced and learned advanced technology and management experiences of foreign countries, and trained a large number of Chinese technicians and management personnel; all of these laid a good foundation for the exploration and exploitation of CBM resources in China.

During a number of foreign cooperation projects, Shanxi Jincheng Panzhuang project and Shanxi Shizhuangnan projectt have achieved ideal development test performance and are most likely to realize large-scale commercial development. Implementation of the two projects will be in conjunction with self-supported Panhe demonstration project of China CBM in the same area.

1) Shanxi Jincheng Panzhuang CBM PSC project

In 3rd, March, 2003, US-China Energy Corporation signed a cooperation contract with China CBM, namely Jincheng, Shanxi CBM resource product-sharing contract. The contract block is located at Qinshui county, Qinshui city, Shanxi Province, with a total area of about 150.8 km^2, and CBM proved reserves of 20.4×10^9 m^3. The contract block has convenient transportation infrastructures, near Taiyuan, Yuci, Changzhi, Jincheng, Gaoping and Huozhou of Shanxi and Linzhou of Henan, and also close to the West-East Gas Pipeline, all of which provide favorable transportatin conditions for CBM transportation and sale. U.S.-China Energy Corporation is one of the foreign companies, the first company to do CBM exploration in China. At the beginning of 2006, the company was merged into Asian America Coal Inc. and became its subsidiary. At present, the National Development and Reform Commission has approved the pre-construction work of this project. First stage of the project is designed to produce 500×10^6 m^3 CBM each year. Follwing the preparation, the development plan will be submitted to the government for approval and upon approval, exploration will start.

2) Shanxi Shizhuangnan CBM PSC project

In 18th, January, 2003, America Greka Energy (international) Corporation signed 4 product-sharing contracts with China CBM to co-exploit CBM resources in Shanxi and Anhui Province. Shanxi Shizhuangnan CBM PSC project is one of them, with a total contract area of 455.286 km^2, proved CBM geological reserves of 13.787×10^9 m^3, and recoverable reserves of 7.486×10^9 m^3. At present, this block has set up power plants and CNG filling stations supplying CBM to Changzhi, Jincheng of Shanxi and other surrounding towns, and started small-scale commercial development.

7.2.1.3. Gas Extraction

Mine gas extraction began in the early 1950s. After 50 years of development, downhole mine gas extraction has developed from mining production safety stage to safe and environment-friendly integrated development extraction. The extraction technology has developed from the single seam extraction and goal extraction of high permeability coal bed to integrated extraction technology suitable for all types of conditions and different mining methods.

According to CBM Development and Utilization"11th Five-Year" Plan, by the first half of 2005, there are 4462 highly gas-content mines and 911 coal mines with extremely high CBM cintent in China. In the major 615 pairs of mines, there are about 200 pairs with extremely high CBM content, 152 pairs with high CBM content and surface fixed gas extraction system 308 sets. In 2005, the amount of downhole CBM extraction was near to 2.3×10^9 m^3, and the extraction volume exceeded 100×10^6 m^3 in Yangquan, Jincheng, Huainan, Songzao, Panjiang, Shuicheng and Fushun mining areas.

Table 7.2 Summary of the international cooperative projects of the Chinese CBM

No.	Project name	Contracted area (km^2)	Signature date	Foreign contractor	Integrating investment (10^3USD)	Note
1	Huaibei	2,662.6	08/01/1998.	Texaco	17,064	Terminated
2	Sanjiao	448.2	29/06/1998	ChevronTexaco	46,220	
3	Sanjiaobei	1,125.7	29/06/1998			
4	Shilou	3,601.7	29/06/1998			Terminated
5	Linxing	3,324.5	29/06/1998		27,000	
6	Fengcheng	1,540.5	13/08/1999	Greka Energy	3,269	
7	Liulin	198.19	12/11/1999	Australian Lowell Oil	3,278	
8	Junggar	2,817	08/11/2000	ChevronTexco /BHP Billiton	15,494	
9	Baode	1,079	08/11/2000			
10	Shenfu	3,001	08/11/2000			
11	Henshanbao	1,708	10/01/2001	U.S. Virgin Oil Co.Inc.	9,470	Terminated
12	Qinnan	2,317.4	16/04/2002	Far East Energy Corporation /ConocoPhillips	9,605	
13	Shouyang	1,962.8	16/04/2002			
14	Laochang, Enhong	1,072.32	03/12/2002	Far East Energy Corporation	5,610	
15	Qinyuan	3,664.5	18/01/2003	Greka Energy	337	
16	Panxie	583.78			264	
17	Shizhuanbei	374.92			267	
18	Shizhuannan	455.29			2,694	
19	Jincheng	150.8	03/03/2003	Sino-American Energy Inc.	31,360	
20	Huangshi	304.583	10/10/2003	China Canada Energy Corporation	714	
21	Mabi	1,371.29	16/07/2004	Asian American gas, Inc	5,400	
22	Guizhou	947	20/05/2005	Asia Canada Energy Inc,	200	
23	Shiloubei	1,015	18/11/2005	Verona Development Corporation		
24	Liuhuanggou	953	30/12/2005	Dynasty Gold Corporation		
Total		36,679.1			178,240	

7.2.2. CBM Utilization in China

CBM utilization in China is in the stage of small scale. CBM utilization mainly concentrates on key state-owned mines with a high CBM production, and the utilization model is mainly to provide CBM for local residents to raise the living standards of residents in the coal mines. Surface extraction utilization is mainly conducted in Shanxi Qinshui Zaoyuan well group, Liaoning Fuxin Liujia well group, Jincheng Panzhuang and Shanxin Qinnan projects and CBM from these areas is transported by manifold trucks and sold to the areas around. In recent years, with increasing awareness to protect environment, the government decontrols gas prices, and CBM attracts more attention to new energy. Therefore, power generation projects and industrial fuel projects are developed in large quantities. The domestic manufacturers of methane generating units include Dynamic Mechanical Plant of Shandong Shengli Oil Field , Jinan Diesel Engine Plant, Jiangsu Nantong Baoju Group and so on. The domestic manufacturers of Industrial gas boilers include Guangdong Disen, Shanghai Xinye, Qingdao Sifang, and Taiyuan Luwei and so on [17].

7.2.2.1. Power Generation

Gas source of CBM generation mainly is coal mine pit mouth CBM. CBM by ground exploitation generally is not used for power generation. According to *Implementation Views to CBM Power Generation* published by National Development and Reform Commission, on the principle, power generated by CBM should be first used in local coal mines, and surplus electricity can be sold to electricity net companies. CBM production has the characteristics of small investment, low operating costs and quick return, and therefore it develops rapidly in China. At present, Chinese main CBM power generation projects are operated by coal mine companies: 120 MW CBM power generation project of Jincheng Coal Group, 20 MW CBM power generation project of Songzao Coal and Electricity Corporation, CBM power generation project of Shuicheng in Guizhou, CBM power generation project of Jixi in Heilongjiang [17].

1) Power generation project of Jincheng Mining Group

Jincheng Mining Group of Shanxi is one of the most successful enterprises in CBM power generation. In 2005, 49.85×10^6 m^3 CBM of Sihe mine is used for power generation. In 2006, 120×10^3 KW CBM power generation project of Jincheng Mining Group of Shanxi started to be constructed. The project uses the fund from Asian Development Bank loans and corporation capital. The first stage finished at the end of 2006, which realized the whole utilization of underground gas in Sihe mine and nearby, and the shortage could be supplemented by surface CBM recovered [2,18].

2) CBM Power generation CDM project in Songzao Coal Electricity Company

The extraction of Songzao Company in 2004 was 121.79×10^6 m^3 (pure amount of methane), but the yearly utilization amount was only 40×10^6 m^3, and the rest was discharged to the air, which not only polluted the air but also wasted resources. Therefore, Songzao Electricity Company had gradually began to implement comprehensive utilization project of the methane, set up power generation and reform or reconstruct civilian supply system from the year 2003. Songzao Power generation CDM project was formally launched in 8^{th} November, 2005, and this project was developped by Chongqing Songzao Electricity Company, Japan's Mitsui Co. Ltd. and Information Institute of State Administration of Work Safety (Coal Information Institute) jointly. According to the plan, by 2008, the extraction amount of Songzao Electricity Company will exceed 200×10^6 m^3 and be 40×10^6 m^3 will be consumed locally, and the electric output will be 120×10^6 KW·h if all the 40 units with total capacity of 20×10^3 KW are put into operation. It is expected that the gas utilization amount of Songzao Electricity Company will be up to 4×10^6 t~5×10^6 t, and Japan's Mitsui Co. Ltd. will buy the company [18].

3) Power generation project in Guizhou Shuicheng

Dawan CBM power generation project of Guizhou Shuicheng Mining Group constructed the first power plant in Guizhou Province. In November, 2003, the first stage of gas power plant with 3,000 KW total capacity began its construction, and in January, 2004, tests started. Because of the favorable benefit in test operation, Guizhou Shuicheng Mining Group set up 16 gas generation units of 500 KW in the second stage. After the operation of second stage project, utilization rate of gas comes to more than 80% and it supplies over 70% of the electricity consumption in the mining area.

4) Power generation project in Heilongjiang Jixi coal mine

The first gas power plant of Heilongjiang Province was put into operation in Chengzihe Coal Mine of Longmei Mine Group Jixi branch in 23rd February, 2006, and this marked the major change from simple extraction to comprehensive utilization in gas control in Heilongjiang Province. Most of the mines in Heilongjiang Jixi Mine are high gas mine, and the drainage in 2005 was about $63×10^6$ m^3. In October 2005, Jixi branch, Shandong Shengdong Group and Jichai Corp invested $770.9×10^3$ USD to build the first gas power plant in Chengzihe Mine of Heilongjiang Province corporately. This plant was installed with 3 generating sets of 500KW, the total installed capacity is 1,500 KW, and the utilization of CBM is $3.30×10^6$ m^3. The electric output can reach $10×10^6$ KW·h per year with $506.3×10^3$ USD of output value and $354.4×10^3$ USD of profits. Jixi Branch has 5 gas exhaust stations, and the extraction capacity is about 1,000 m^3/min. If all the stations are used to generate electricity, the total installed capacity is $25×10^3$ KW, and the electric output is $140×10^6$ KW·h per year. At present, Jixi branch is constructing 3 gas power plants with total installed capacity of $10×10^3$ KW, annual power generation amount of $60×10^6$ KW·h, output value of $3.038×10^6$ USD and profit of $2.1266×10^6$ USD [19].

7.2.2.2. Industrial Utilization

The industrial utilization of CBM is mainly used for industrial fuel and for chemical products. CBM was previously used mainly to produce carbon black and methanal. Currently it is used as industrial fuel to replace industrial coal gas, natural gas, LNG or coal. The major domestic CBM industrial utilization projects are: project of Tiefa Coal Industry Group supplying CBM to Taoci City of Faku County and alumina baking project of CBM utilization in Yangquan [17].

1) Project of Tiefa Coal Industry Group supplying CBM to Taoci City of Faku County

The project is part of the CBM CDM project, cooperated by Tiefa Coal Industry Group (Tiemei Group) and Japanese Mitsui Corporation. The total investment of this project is $253.2×10^6$ USD, inlcuding the investment of Aode Group of $151.9×10^6$ USD, and the investment of Tiefa Coal Industry Group of $10.13×10^6$ USD in the auxiliary project. This project is located in the Tiefa Coal Industry Group in Diaobingshan City of Liaoning Province. The technological process is in transporting the gas into $80×10^3$ m^3 tanks of Aode Group through pressured feeding equipment, and then the gas will be transported to Taoci City of Faku County through pipelines of a length of 8 km. Supply capacity of this project is $200×10^3$ m^3/d [20].

2) Alumina baking project of CBM utilization in Yangquan

In November, 2006, CAMCO agreed to cooperate with Yangquan Coal Industry Group in CBM area, wind energy area and solar energy area and took CDM project as a starting point of cooperation. The project is one of the first two jiont projects and would be operated with CDM mechanism. Yangquan Coal Industry (Group) Co. LTD plans to build an alumina plant with annual production ability of $800×10^3$ t, and the main equipment is a roaster to generate the heat for materials separation and process via CBM conbustion. The alumina plant will use CBM of $42×10^6$ m^3 every year, and can create emission reduction about $750×10^3$ t of carbon dioxide equivalent every year [21].

7.2.2.3. Civil Utilization

Underground extraction produces the CBM with the average CH_4 concentration of 30~50%, and could be straightly supplied to mining residents, restaurants, hospitals and schools. Because of the limited residents in mining areas, CBM large-scale civil utilization must be tended to big cities. At present, main domestic CBM civil utilization projects are Fuxin CBM project and Tiemei Group supplying to Diaobingshan CBM project [17].

1) Project of Fuxin Mine supplying CBM to Fuxin City

The Project of Fuxin Mine supplying CBM to Fuxin City (using CBM instead of coal gas) started in 1998 made safe and clean energy available to the residents. Up to 1st March, 2003, Fuxin City Gas Company has supplied CBM to 70,000 residents of the city, and the maximum gas supply could reach $170×10^3$ m^3 per day in one year. The third period started in 2003, gas supply could reach $216.4×10^3$ m^3 per day, and the service period is 30 years.

2) Project of Tiefa Coal Industry Group supplying CBM to Tiefa

The project is part of CBM CDM project which is cooperated by Tiefa Coal Industry Group and Japanese Mitsui Corporation. The total investment is $30.00×10^6$ USD, including the investment from Tieling Government of $16.96×10^6$ USD, the investment from Japanese GAP of $7.59×10^6$

USD and the investment in the auxiliary project from Tiefa Coal Industry Group of 4.18×10^6 USD. After the operation of the project, daily gas supplying ability would be 150×10^3 m^3/d [20].

7.2.3. International Aid to the Chinese CBM

Since the 1980s, an environmental problem in the whole world has attracted much attention. The most critical problem is that the emission of the greenhouse gas (CO_2 etc.) destroys the ozonosphere, which leads to global warming. Having realized the importance of the CBM development and utilization for environmental protection, many international organizations actively support the CBM projects in China, such as UNDP, APEC, USEPA and so on.

7.2.3.1. EU-China Energy and Environment Programme (EEP)

EU-China Energy and Environment Programme (EEP) is an international cooperation project for strengthening the cooperation of both sides in energy domain, according to the cooperation agreement of Chinese government and the EU Commission. Implementation period is May, 2003 to May, 2008, and now the programme is extended to 2009. Total investment of the project is 42.9 million euros, with 20 million euros from EU. The project includes three parts, which are energy conservation, renewable energy and natural gas, and aims at improving energy utilization efficiency, promoting the utilization of renewable energy and fostering and developing natural gas market to promote the utilization of natural gas. Feasibility Study of Coal Bed Methane is one of the study tasks imbursed by EU-China Energy and Environment Programme. Its aim is to evaluate the technical and economic feasibility of Chinese CBM production. According to the conclusion of the project, EU will make decision on investment in Chinese CBM pilot test.

7.2.3.2. Global Environmental Fund (GEF) Project

GEF is mainly used to aid the developing countries to protect environment mainly in four fields: global warming, international water domain pollution, biodiversity damage and ozonosphere damage. UNDP, UNEP and WB perform GEF projects jointly.

In 1991, UNDP determined to provide China with aid to “improve utilization efficiency of coal and to protect the environment”. The project includes two sub-projects, namely “Chinese CBM resource exploitation” and “CBM resource exploration in deep coal seams”. In June, 1992, the project “Chinese CBM resource exploitation” was changed to GEF project (CPR/92/G3), and obtained aid of 10×10^6 USD from GEF. Implementation of GEF has not only improved Chinese ability of independent CBM commercial exploitation, but also promoted international organizations, foreign corporations, especially Chinese government, to pay more attention to the effects of CBM exploitation on the increase in new energy, improvement of coal mine safety and greenhouse gas emission reduction [22].

7.2.3.3. UNDP Project

In 1993, the U.N. offered 1.30×10^6 USD to China through UNDP to aid the project “Deep CBM exploitation in China” of Huabei Petroleum Geology Bureau. The implementation location of this project is at Yangjiaping, Liulin County, Shanxi Province, which belongs to Hedong coalfield. In the restrictive region of the CBM exploration and development, 7 gas wells had been disposed to form well network, performed emission-exploitation test and obtained steady gas production. Average single well output could reach 1000 m^3/d~3000 m^3/d, and the maximum was 7,050 m^3/d. According to the exploration evaluation result, Hedong and Weibei coal-bearing regions in the Ordos Basin are the most favorable regions for CBM exploration and development and has become heat point regions of CBM exploration and development in China [22].

7.2.3.4. USEPA Project

To encourage the Chinese coal mines to enhance the recovery and utilization of underground ventilation gas and decrease greenhouse gas emission, USEPA determined to establish the China Coal Bed Methane Information Center jointly with the former Chinese Ministry of Coal Industry. The China Coal Bed Methane Information Center cooperated with USEPA to complete “Joint report of CBM exploitation prospect in China” and organized to publish “CBM Exploitation and Utilization Handbook”. It was also responsible for publishing “China Coal Bed Methane Journal (in Chinese and English). To speed up the CBM development and utilization in the Chinese coalmine areas, USEPA and the China Coal Information Institute (CCII) jointly established a new cooperative project, “Coal Mine Methane Market Development” which would be completed within two years. The implementation of the project greatly promoted the CBM international cooperation and establishment and operation of CBM projects in Chinese coal mining areas [22].

7.2.3.5. USDOE Project

In November 1994, USDOE come to term with National Science and Technology Commission of China to co-perform the project "National research of Chinese climate change". The aim was to estimate the main effects of climate change and bring forward suggestions to solve the problem. On the basis of this project, USDOE supported the project "Strategy research of greenhouse gas emission-reduction technical evaluation and development" and its sub-project "Strategy research of CBM exploitation and utilization technical evaluation and development". The report advised that the emphasis of Chinese CBM exploitation and utilization should be in coal mines, and exhibit three pilot projects that had spreading potential and had representative and pioneering function in the area [22].

7.2.3.6. GAP (Green Aid Plan) Project

GAP project was proposed by Japanese government in 1991, with a total project investment of 7×10^6 USD and implement time limited to the period of 1993~2000. The assistant targets of GAP were Southeast Asian nations and China, and would assist environmental protection projects, clean coal utilization and exhausted gas purification projects of relative countries in the ways of offering equipment and technology. The CBM exploitation and utilization was just one aspect of GAP project. CBM recovery and utilization demonstration project in Tiefa coal mine is one of the sub-projects. This project was approved and started in February 1998, operated by Tiefa Coal Industry Group Corporation Limited during 1999~2002. After the operation of the project, CBM of underground drainage utilization rate was improved greatly [22].

7.2.3.7. Clean Development Mechanism (CDM) Project

CDM is one of the three agile frames under the Kyoto Protocol (KP). Its main content is to allow Annex I parties and non-Annex I parties of United Nations Framework Convention on Climate Change to cooperate on greenhouse gas (such as CO_2 and CH4) emission reduction projects. Annex I Parties can use certified emission reduction (CER) to fulfill their promise according to KP Article 3. The core of CDM is to allow developed countries and developing countries to transfer and obtain CERs based on investment projects. China approved the KP in 2002, established national CDM management organization (DNA) in 2003, and published Measures for Operation and Management of Clean Development Mechanism Projects in China in 2004. By June 2006, there have been 15 coal mines developing or ready to develop CDM project, such as Tiefa, Songzao, Huainan, Huaibei, Jincheng, Pingdingshan, Yangquan, Hegang, Ningxia and so on [22].

7.2.3.8. Abandoned Mine Methane (AMM) Project

AMM Extraction and Utilization Project was funded by British Department of Trade & Industry, and cooperated by The University of Nottingham, Wardell Armstrong Corporation, China Coal Information Institute Xi'an Branch and China University of Mining & Technology. The project started in January 2001 and ended in August 2002. The aim of this project was to research the drainage and utilization foreground of Chinese AMM, and to accelerate Sino-UK technology cooperation and exploitation-utilization of Chinese AMM.

In China, most of abandoned coalmines are located at high-gas diggings, with abundant reserves and underground drainage system and upground transportation-distribution system generally. These conditions could not only assure stable supply, but also reduce infrastructure investment. Therefore, Chinese AMM extraction and utilization projects have considerablel prospect [22].

7.2.3.9. Asian Development Bank (ADB) Project

Asian Development Bank (ADB) actively supports the development of Chinese clean fuel and greenhouse gas emission reduction, and CBM is one of its mainly supporting areas in energy domain. At the beginning of the 1990s, Asian Development Bank began to supply assisstant projects for Chinese CBM exploration and development, including " CBM Development Survey in China", "Feasibility Study Project of Yangquan Wukuang CBM pilot project" and "Pre-Feasibility Study Project of CBM Development in Yangquan(Hanzhuang-Shouyang)" [23].

In 2004, Asian Development Bank agreed to provide two loans respectively to help Chinese government to develop coal mine methane comprehensive development and utilization in Liaoning and Shanxi, with projects loans of 70×10^6 USD and 117×10^6 USD. The project in Liaoning would set up underground CBM production and storage equipment in Fuxin, rebuild the fuel and central heating system for 6 cities in Liaoning Province, and close small-scale coal-burning boilers. By the collection and utilization of methane in Fuxin region, the implement of the project could reduce greenhouse gas emission and improve local environment by using clean energy. The project in Shanxi includes CBM development and utilization project of Jincheng Coal Group, long-distance pipeline project of Shanxi Energy Industry Group and CBM comprehensive utilization project of Jincheng City. Implementation of this project would greatly promote CBM utilization efficiency of Jincheng Coal Group, and choosing parts of Yangcheng and Qinshui coal mines, CBM of Shanxi Energy Industry Group and Jincheng Coal Group as source, construct urban gas pipeline network of 6 counties in Jincheng to supply to companies and residents.

7.3. Development Situation of CBM Industry in China

7.3.1. Development Stages of CBM Industry in China

The development of CBM industry could not be too quick. Countries with mature CBM industry all have long development period. Development of CBM industry could be divided into 5 stages: geological block choosing stage, exploration and evaluation stage, small-scale commercial development stage, large-scale commercial development stage and mature stage.

At geological area choosing stage, according to the general investigation of coal resource or coal and gas resources data from coal geological exploration, CBM companies would implement comprehensive study, evaluate the potentiality of CBM resources and choose favorable coal-bearing basins or blocks. CBM companies could choose to continue holding or abandoning pre-perspecting right. They could also choose to apply for new perspecting right to enter into new areas.

At exploration and evaluation stage, CBM companies implement further exploration engineering in favorable coal-bearing basins or blocks, choose favorable blocks, and obtain CBM proved reserves through single well and/or small-scale well net development test. At the same time, economic evaluation is conducted and decision to start large-scale commercial development is made.

At small-scale commercial development stage, under the limitation of CBM infrastructure, produced CBM is minly transported to local or near regions by tanker transportation. So the CBM market scale is very small. There are only a few CBM supplying companies. Laws and supervision system are not perfectly in place with great investment risk.

At large-scale commercial development stage, CBM infrastructure is improved. Produced CBM is transported outside by pipeline network. CBM market scale increases quickly. There are more CBM supplying companies with perfect laws and supervision system.

At mature stage, there is more favorable CBM infrastructure. More companies enter into CBM market, and CBM trade companies appear. Companies operating CBM infrastructure do not do CBM purchase and sale business any more, but just supply transportation and storage services. There is plenty of competition in CBM retail domain with even perfect laws and supervision.

Chinese CBM industry is striding from small-scale commercial development stage to large-scale commercial development stage. But, it is unbalanced in different regions and in different companies.

7.3.2. Situation Analysis about CBM Exploration in China

Chinese CBM surface exploration has lasted for about 20 years. Up to now, the state has registered 64 CBM exploration blocks in 12 provinces or municipalities, with a total exploration area of 81,810.3 km^2 [24]. Through exploration activities in these CBM blocks, relative companies have elementally ascertained the blocks with perfect commercial prospect, and have got some CBM proved geological reserves.

CBM exploration progress has direct effects on company input. CNPC and China CBM are the two largest companies investing in CBM exploration projects. CNPC supplies CBM exploration using equity. Total investment in past years comes to 141.7×10^6 USD. China CBM implements

CBM exploration by attracting foreign capital. Taking 2006 for example, 27 joint projects of China CBM attracted total foreign investment of about 71.24×10^6 USD [2], most of which are invested in exploring activities in cooperation blocks. These two companies both have got important CBM exploration progress in their persepcting blocks.

7.3.3. Situation Analysis about CBM Development in China

After ten-year practice of CBM surface development, China has realized small-scale commercial development in the south of Qinshui Basin in Shanxi and Liujia, Fuxin in Liaoning. Main reasons for the success of the projects are as follows:

1) Good CBM geological conditions. CBM geological condition determines CBM production ability, drilling investment and the following activities. Favorable geological conditions could guarantee a higher yield and input-output ratio. South of Qinshui Basin and Liujia Fuxin blocks both have the characteristics of thick coal seam, shallow coal seam burial depth, good seam permeability and high gas saturation, and are the best areas for CBM ground development in China.

2) Good market conditions. These projects all locate at or near towns, and have great civilian market potential. Advatages of civilian CBM use is more than power generation and used as fuel. Surface CBM could be wholely sold, and produce great economic benefits.

3) Good transport facilities. At small-scale commercial development stage, CBM is mainly transported by tankers, and good land transport condition is very important. If there are national highways, provincial highways and other highway between such projects and target market, it will make it greatly convenient for CBM transportation.

7.3.4. Situation Analysis about CBM Utilization in China

CBM utilization in China includes two parts, namely CBM utilization of surface extraction and underground gas extraction. Surface extraction aims at profits. CBM companies put more stess in discovering stable CBM market, and the utilization ratio of surface extraction is very high.

Underground CBM extraction mainly aims at resolving mine ventilation and ensuring production safety. Commercial utilization of CBM is very late, with low utilization ratio. Underground CBM extraction is restricted by low methane concentration, mainly used for power generation, industrial fuel and residenence. Power generation is an important way to improve utilization ratio.

Sihe CBM power plant project of Jincheng Coal Group is one of the projects which successfully improving CBM utilization ratio of underground extraction. The main reasons for its success are as follows.

1) Taking full advantage of foreign funds. The construction of large-scale CBM power plant needs a number of funds. Though companies can make use of their own capital, they still need the support of foreign funds to the projects. This project succeeded to apply loan from Asian Development Bank. Then the construction scale comes to 120×10^3 KW. When finished, it would entirely solve the utilization problems of underground extraction CBM in Sihe Mine and other mines nearby.

2) Actively taking advantage of CDM mechanism to improve project yield. CBM power generation is effected by low electricity price in electricity net, which results in low yield and is the main restriction to scale of CBM power plants. This project took full advantage of CDM mechanism, improving project yield by selling emission reduction. In 2004, World Bank Carbon Fund bought 4.5×10^6 t emission reduction and 1.5×10^6 t options of the project. In 2005, Japan Carbon Fund (JCF) also purchased 2.4×10^6 t emission reduction of the project [2].

7.3.5. Current CBM Infrastructure in China

CBM infrastructure is the key factor affecting CBM large-scale commercial development in China. Because CBM and natural gas could be mixed and transported, CBM infrastructure includes natural gas pipeline network and im-house facilities.

In the context of the rapid development of natural gas industry in China, CBM industry gets a good opportunity to use natural gas pipeline network. Along with the operation of West-East Gas Pipeline, North-South Gas Pipeline and Ocean-Land Gas Pipeline, the state would promote the construction of natural gas pipelines, aiming at setting up a pipeline network connecting domestic gas pipelines, import gas pipelines and seaside gas pipelines to form a complete regional and even national natural gas supplying network. Construction of these natural gas pipelines provides perfect conditions for development and utilization of CBM. As mentioned above, the West-East Gas Pipeline and Shanjing Pipeline are the two natural gas pipelines with most utilization potential.

West-East Pipeline is 1,948 km long, starting from Xinjiang Lunnan in the west to Shanghai Baihe Towm in the east, passing through Xinjiang, Ningxia, Shaanxi, Shanxi, Henan, Anhui, Jiangsu, Shanghai and Zhegjiang. The covered areas include the central-china, east-china and yangtze delta area, and the designed annual transportation capability is 12×10^9 m^3.

b. Shaanxi-Beijing Pipeline

Shaanxi-Beijing Pipeline is 935.4 km long, starting from Shaanxi Province in the west to Caiyu town of Daxing district of Beijing in the east, passing through Mongolia, Shanxi, Hebei provinces, that is, passing through southeast edge of Maowusu Desert, Loess Plateau of Shanxi and Shaanxi, Luliang Mountains, Taihang Mountains and North China Plain. The designed annual transportation capability is 12×10^9 m^3.

Moreover, thinking of the factors of location, CBM production scale and others, some CBM companies choose to construct pipeline of their own. At present, completed and constructing pipelines are ”Lizhuang-Jincheng-Mine” CBM Pipeline of Jincheng Coal Group and “Duanshi-Jincheng-Boai” CBM Pipeline of China CBM. There is a strong demand for CBM in Shanxi. The two pipelines choose CBM in the south of Qinshui Basin as gas source, and supply CBM to surrounding cities and towns.

7.3.6. Policy and Law Situation Analysis of CBM Industry in China

7.3.6.1. CBM Resources Management Laws and Regulations

At present, upstream domain of Chinese CBM industry is supervised by a legal framework and many specific regulations, including *Mineral Resources Law*, *Mineral Resources Law Implementation Details*, *Mineral Resources Exploration Block Registration Management Method*, *Mineral Resources Exploitation Registration Management Method*, *Transference Management Method of Exploration Right and Exploitation Right* and so on.

Mineral Resources Law is a legal framework, promulgated and implemented in 1986, amended in 1996. *Mineral Resources Law* aims at the development of the mineral industries, to improve exploration, development, utilization and protection of mineral resources, to ensure current and long-term demand for the country to mineral resources. *Mineral Resources Law* is the first law about mineral resource in China. It states definitely that CBM is a specific mineral commodity.

Mineral Resources Law Implementation Details, *Mineral Resources Exploration Block Registration Management Method*, *Mineral Resources Exploitation Registration Management Method*, and *Transference Management Method of Exploration Right and Exploitation Right* are special regulations as parts of the legal framework. *Mineral Resources Law Implementation Details* was promulgated and implemented in 1994, aiming at materially implementing *Mineral Resources Law*, strengthening management to mineral exploration and exploitation. For the first time, *Mineral Resources Law Implementation Details* states a set of procedures and rules about exploration and exploitation right application of mineral resources and measures to various violations. *Mineral Resources Exploration Block Registration Management Method* was promulgated and implemented in 1998, aiming at strengthening management to exploration of mineral resources, protecting the interest of legitimate right, upkeeping the order of mineral resources exploration and improving the development of mineral industries. *Mineral Resources Exploration Block Registration Management Method* enriches and updates original rules about exploration application, which standardizes and opens the procedures of license application. The law also states new fiscal system about exploration industry including foreign companies, and adds 34 mineral resources as accessory. *Mineral Resources Exploitation Registration Management Method* was promulgated and implemented in 1998, aiming at strengthening the management to exploitation of mineral resources, protecting the interest of legitimate right, upkeeping the order of mineral resources exploration and improving the development of mineral industries. *Mineral Resources Exploration Block Registration Management Method* enriches and updates original rules about exploration application, which standardizes and opens the procedures of license application.

The law also states new fiscal system about exploration industry including foreign companies, and adds 34 mineral resources as accessory. *Transference Management Method of Exploration Right and Exploitation Right* was promulgated and implemented in 1998, aiming at strengthening the management to transference of exploration right and exploitation right, and protecting the legitimate interest of exploration right and exploitation right. For the first time, *Transference Management Method of Exploration Right and Exploitation Right* states a set of procedures and rules about application, examination and approval for the transference of exploration right and exploitation right under license management. Main contents of these laws and regulations include:

1) CBM exploration and exploitation must be approved by relative departments

Mineral Resources Law states that "companies implementing mineral resources exploration and exploitation must meet the conditions for qualification". According to the above-mentioned law, companies who implement CBM exploration and exploitation, regardless of what ownership, must be approved by relative departments before access to CBM exploration and exploitation domain.

2) Implement first level of State Management System to CBM exploration and exploitation

According to Chinese laws and regulations about mineral resources, CBM exploration and exploitation are managed by the first level of state management system. Entities who engage oil and gas exploration and exploitation, can only apply to The Ministry of Land and Resources who has the right to award oil and gas exploration license and exploitation license.

3) Entities who Iiplement CBM exploration and exploitation must get exploration license or exploitation license

According to Chinese laws and regulations about mineral resources, entities who get qualification must submit license application and relative files (such as exploration scheme and capital evidence), and can begin exploration only when approved after strict examination. Getting CBM reserves and being put on records by the Ministry of Land and Resources after investment and exploration, entities who have perspecting right should submit perspecting application book and other materials (including development and utilization scheme of mineral resources, reserve report and approval files approved by mineral resource reserves management department, environmental effect evaluation report and suggestion of environmental protection department to the report, capital evidence and so o), to apply for perspecting right. After strict examination, approving register and award perspecting license by The Ministry of Land and Resources, CBM companies can become entities with perspecting right and implement exploitation.

4) The Ministry of Land and Resources and provincial ministry of land and resources together supervise the proper use of CBM exploration right.

Mineral Resources Law states that, geology and mineral resources management departments of provinces, autonomous regions, or municipalities directly under the central government, are in charge of monitoring and management to exploration and exploitation of local mineral resources.

5) The Ministry of Land and Resources has the power to administrative penalty to illegal activities

Mineral Resources Exploration Block Registration Management Method and *Mineral Resources Exploitation Registration Management Method* respectively state that, the State Council geology and mineral resources management department has the right to punish illegal activities.

6) Imposition method of mining royalties

The mining royalties in connection with CBM exploitation are paid in terms of the regulations concerning the conventional natural gas in land, that is to say:

a. If annual CBM production is not more than 1×10^9 m^3, the mining royalties are exempted;

b. If annual CBM production is between 1×10^9 m^3 and 2.5×10^9 m^3, the mining royalties' rate is 1%;

c. If annual CBM production is between 2.5×10^9 m^3 and 5×10^9 m^3, the mining royalties' rate is

2%;

d. If annual CBM production exceeds 5×10^9 m^3, the mining royalties are 3%.

7.3.6.2. CBM Tax Policies

1) VAT and resources tax policies

The Notice on Tax Policy Issues to Accelerate the CBM Extraction (FT [2007] 16) published by the State Ministry of Finance and State Administration of Taxation states that the VAT return-after-imposition policy is carried out aiming at the VAT ordinary taxpayers of the CBM extraction enterprises and that CBM campanies performing surface extraction do not need to pay resources tax.

2) Corporate income tax

According to the regulation of Ministry of Finance (FT [1996] 62), the regulations concerning the corporate income tax issues for cooperative exploitation of petroleum resources are the same with the enterprises that extract the Chinese CBM resources onshore. The tax will be exempted in the first 2 years starting from their profit-making year and reduced by 50% in the following three years. The enterprises that independently carry out the CBM exploitation activities pay the income tax at the rate of 25%.

3) Custom duty

The Regulation on Exemption from Import Tax for the CBM Exploration and Development Projects Importing Goods and Materials (FC[2006]13) published by the Ministry of Finance and the General Customs Administration states that if China CBM and its cooperators that carry out the CBM exploration and development projects in China import equipments, instruments, accessories, tools that can't be produced (or can't be produced based on the requirements) in China and are directly used for exploration and development operation, the import tax and the import VAT are exempted.

4) Resources compensation fee

The State Council promulgated the Mineral Resources Compensation Collection Management Regulation (State Council Decree No. 150) states that exploitation of mineral resources in China and other jurisdictional waters should pay the mineral resources compensation tax in accordance with this regulation unless that is stipulated by other laws and regulations. The rate of CBM mineral resources compensation fee is 1%.

7.3.6.3. CBM Price Policy

According to Notification [DRP (2007) 826] issued by the State Development and Reform Commission, the price of CBM for residence that doesn't enter the urban public distribution network is decided in negotiation between supplier and consumers, and the price of the civil CBM that enters the urban distribution network and is under local government administration is set up in accordance with the principle to keep reasonable comparative price per equal caloric value similar to such alternative fuel as natural gas, coal gas, LNG.

7.3.6.4. CBM External Cooperation Policies

Based on the experiences of offshore oil, the Chinese government approved the establishment of the China CBM in 1996 and granted it external cooperation franchise to carry out CBM exploration, development and production. Since then, the Chinese foreign cooperation in the development of CBM implements foreign policy franchise system. To meet the WTO requirements, in the year 2001, the Chinese government revised the People's Republic of China External Cooperative Exploitation of Onshore Oil and Natural Gas Resources and clearly stipulated that external cooperative exploitation of the CBM resources can be uniquely operated by China CBM. In September, 2007, the Chinese government once again revised the People's Republic of China External Cooperative Exploitation of Onshore Oil and Natural Gas Resources, allowing other companies appointed by the State Council to operate CBM international cooperation. CBM international cooperation license granting began to limitedly open to other companies. Currently, The State Council has not grant the CBM international cooperation license to other companies.

The People's Republic of China Mineral Resources Law and the People's Republic of China External Cooperative Exploitation of Onshore Oil and Natural Gas Resources state together the basic principle which should be abided by the Chinese CBM international cooperation as follows: resources are state-owned, mining activities and facilities are subject to the jurisdiction of host country of the resources, priority is given to host country, natural environment is protected and ecological balance is maintained.

7.3.6.5. Other CBM Favorable Policies

According to the Implementation Opinions of the Ministry of Finance on the subsidies for the CBM (gas) Development and Utilization (FC [2007] 114) issued by the Ministry of Finance, the government will grant the subsidy to the CBM (including gas) extraction enterprises within the boundary of China with the standard of 0.0253 USD/m^3 for pure CBM.

According to the Notice of Implementation of Utilizing the CBM (gas) to Generate Electricity issued by the State Development and Reform Commission (DRE [2007] 721), the surplus electricity of the CBM (gas) power plant is purchased by the power grid enterprises. Power plants don’t participate in the market competition and do not undertake grid peaking. The network price of the power plant is decided in accordance with local desulphated coal power unit base network electricity price of 2005 with subsidized electricity price added.

7.3.6.6. Coordination Policy of CBM Development and Coal Development

CBM resources reserve in coal seam, so there is conflicting possibility between the development of CBM and exploitation of coal. In 17th April, 2007, The Ministry of Land and Resources stated Notice about Strengthening the Management of Coal and CBM Resources Comprehensive Exploration and Exploitation, and brought forward measures to settle this problem. New coal exploration right do not include the access to the special CBM exploration and exploitation areas marked and proclaimed by the state, and the penalty to entities which have exploration right but have not put in reqired minimum investment is serious. As for the existing overlapping mining right, the two sides should solve the problem through negotiation. If no agreement is reached, land and resources management department should mediate. If no agreement is reached still, support is on the side of coal production companies in schemed mines by the state to implement comprehensive exploration and exploitation of CBM resources.

7.4. Bottle Neck of Chinese CBM Development

7.4.1. Challenge from Alternative Energy

CBM as a kind of unconventional natural gas energy, its development will certainly compete with the conventional energy. In China, the direct competitors for CBM are coal and natural gas. CBM reservoir is coal, and coal resources are also rich in the regions with high CBM production and accumulation, so their markets are overlapped to some extent. In addition, the Chinese coal has its own advantages, including mature and enormous market, low price, which is result in difficulty in CBM marketing. Currently, the level of the Chinese gas development and utilization is still low, and is only less than 3% of the primary energy consumption. However, with the development of Chinese economy and increasing demand for energy security and environmental awareness, especially with the completion of the West-East Ppeline, the natural gas resource development has entered the fast track of development and occupied the market ahead of time. Moreover, in addition to its great initial yield and quick profits, the natural gas’s drilling and production technology is relatively simple and doesn’t need stimulation in general, so it is more preferred by the enterprises, resulting in severe market competition.

7.4.2. Lack of Infrastructure

The same as in the areas of natural gas, the CBM development needs the coordination between the transmission and distribution network construction and the utilization facilities reformation. One of the important reasons that the United States can develop its CBM industry rapidly in 10 years is its advanced gas pipeline network and utilization facilities, which has been making great contribution to the closer integration of the production and utilization, and thus reduced initial cost and increased later economic benefits are achieved in a quick way. Currently, the Chinese CBM infrastructure is insuficient. Transmission and distribution network is incomplete. The Chinese natural gas industry started relatively late and its supporting transmission and distribution network isn’t complete. At present, only some areas have regional gas transmission pipeline networks. The lack of natural gas transmission and distribution network in Chinese CBM development areas with great potential, severely limits large-scale commercial development of CBM in China. At present, in areas with the conditions for large-scale commercial development, Chinese CBM companies are constructing long-distance pipelines only for transportation of CBM

7.4.3. Insufficient Innovation in Theory and Technology

The geological conditions of the Chinese coalfields are complicated. Most coal seams have the characteristics of low porosity, low permeability, low saturation, high gas content and strong heterogeneity [43]. CBM large-scale development is still at the early stage. There are key problems both in theoretical and technical aspects [1]. The characteristics of the CBM industry are high input, high risk and high technology, and its development depends on the massive input in the early stage, more advanced technology and equipment. At present, the theoretical and technological researches of the CBM exploration and development have noy received necessary support, lacking adequate labor force, infrastructure and funds. Moreover, some fundamental theory, key technology and equipments urgently need improving. The Chinese government is paying more attention to the research work of CBM exploration and development technology. In 26th, 2007, CBM State Engineering Research Center was set up. Long-term key technology project of the state---large-scale Oil and Gas Field and CBM Development is also to be started [1]. This work would help to solve the current problem of insufficient innovation of theory and technology.

7.4.4. Management of CBM Industry needs Improvement

As a separate industry, CBM exploration and development should be ruled by perfect laws and regulations, so as to definitude separate right and obligation of CBM industry parties and promote reasonable development of CBM industry. The current Chinese CBM laws and regulations have the problems of low level, limited restrictions and no law system in the aspect. The management of Chinese CBM resources exploration, development, production, transportation and sales is mainly according to regulations of the State Council and departments. These rules and regulations belong to second-level legal system. Because of lack of support from first-level law, the legal system effect is low, which could easily cause weak implementation. Moreover, there are many blanks in a lot of important domains of CBM industry middle and lower reaches, which causes the lack of long-term steady investment and management environment in CBM industry middle and lower reaches. The incertitude and investment risk are been increased, so not benefit to the development of this domain.

7.5. Suggestion for Chinese CBM Policies and Laws

7.5.1. Government Supported Investment

7.5.1.1. Scientific Research Investment

The Chinese reservoir conditions are complex, which makes the exploitation rather difficult and the technological supports of the CBM extraction and utilization are insufficient. There exist many critical theoretical and technical problems. Some fundamental theoretical researches also needs to be strengthened, including CBM existence form and reservoir formation rugulation, gas control factors of the CBM regions with high permeability and rich concentration as well as mining coal after exploiting CBM, etc. In addition to fundamental research and technology integration, in order to lay the foundation for the Chinese CBM medium and long-term development of science and technology, we should attach importance to other leading-edge technology researches, including the use of geophysical methods to evaluate the gas content in the coal bed, post fracture response evaluation of the CBM wells and fracture monitoring technology, the CBM recovery enhance technology, the CBM exploitation technology in deep coal seams, conventional natural gas and CBM simultaneous exploitation technology, the CBM efficiency improvement technology and high value-added processing and utilization technology of the CBM. The state should utilize the Major National Fundamental Research Program, the National Five-year Program for Tackling Key Problems, Natural Science Fund for Key Project Plan to preferredly arrange the CBM fundamental theoretical research to study the key scientific issues that constraint the development of the Chinese CBM and accelerate the formation and development of the Chinese CBM industry.

7.5.1.2. Investment on Pilot Test

There are many positive effects by investment on pilot test of Chinese government. Through the whole process of the test of CBM surface development, China has got some valuable experiences in CBM development technology and management, which accumulates information for CBM large-scale development. At present, main pilot test areas getting support from the government are located at Qinshui Basin. The difference of geology and location of various regions limits the demonstration effects of the pilot test. So, the state needs to increase investment in favorable areas with perfect geological conditions in CBM exploration and development, and focus on rapid increase in production, and then promote the large-scale development of local CBM industry.

7.5.2. Completion of CBM Laws and Regulations

CBM as a new kind of mineral, its geological formation conditions and development technology system are different from that of the solid coal and that of the liquid petroleum and natural gas, but it relies on the coal as its geological carrier and share the pipelines and terminal users with the natural gas, and therefore special independent and dependent relationship exist among CBM, coal, petroleum and natural gas. Therefore, from the prospect of the industry development, the CBM especially needs a harmonious policy environment.

Along with the development of CBM industry, gaps between the industry and law framework must appear where no law supervises. Because of the intimate relationship of CBM and natural gas, the government could publish a law in allusion to CBM and natural gas which could include all the industry chain, so as to lead the good development of CBM industry.

7.5.3. Implementation of CBM Encouraging Policies

Due to the temporary deficiencies of the technology, theory and equipment, the lack of scaled development and immature market, the main goal of the early establishment of the CBM industry should aim at achieving its important social function in the environmental protection and mine safety, and the economic benefits should be secondary. However, the CBM development and utilization enterprises as market-oriented economic entities are bound to conform to the cost-effective lever, otherwise, from the economic point of view, development and utilization of the CBM is not feasible. The government needs to set up encouraging policies at the early stage of CBM development to balance the contradiction between the social benefits enjoyed by whole society and the economic benefits enjoyed by the enterprise.

7.5.3.1. Financing

The CBM industry development must have a reliable financing system as guarantee. In addition to direct investment, it is necessary for the government to support the CBM enterprises to use the domestic and foreign financing channels. Currently, the comparatively feasible financing channels include domestic loans, specific project financing and foreign investment.

1) Domestic Loan

Domestic bank loan is low-cost, fast-cycle and flexible, but compared with mature industry projects, the CBM projects have no advantage in obtaining the domestic bank loans. With the intenfied banking reform, commercial banks are more restricted in offering subsidized loans. Therefore, the state needs to ask for more support from the policy-oriented banks to the CBM industry.

2) Specific Project Financing

Project financing is very popular internationally, and the Chinese oil and gas enterprises often adopt this method. The projects that need project financing are usually large-scale projects and are started by co-financing of a number of companies in general. For the key CBM projects in the favorable areas, the state should actively coordinate relevant enterprises to establish cooperative mechanism, and help them to lower project cost, and guide them to focus on the completion of the project.

3) Foreign Investment

China's huge CBM resource and market potential are the material basis for attracting foreign investors to interest in China's CBM industry. The project economic efficiency must be improved. The state government needs to do well in supporting the CBM potential areas that the foreign capital interest in, preferred tax policies; infrastructures such as communication, environmental protection, transportation and services; natural gas pipeline network construction; natural gas storage project and natural gas utilization projects. In addition, such measures also include lowering the entering threshold of collaborators, broadening the scope of cooperation (such as underground gas drainage), encouraging the foreign partners to use new technology (such as horizontal and directional wells drilling technology.), increasing the physical workload input of collaborators, reducing the costs for signing, training and assistance correspondingly, establishing supervisory mechanism for foreign cooperation, improving and strictly implementing the withdrawal mechanism and mechanism for terminatation of contracts of insufficient investment timely.

7.5.3.2. Tax and Subsidy

The key reason for the success of the United States CBM industry policies is that it is established in accordance with the conventional gas policies, but more favorable, and this has promoted the formation and fast development of the CBM industry. Presently, China learns from the foreign experiences and makes some economical preferred policies. Judging from the results of the economic evaluations, tax reduction could greatly improve the economic benefits. Moreover, the amount of tax cuts required for the CBM development is very limited.

The provision of subsidies is the most effective tool for Governments to regulate and control the development of CBM. In this respect we advocate that the Government applies a subsidy policy for the development of the CBM industry, whereby the geological and geographical conditions of the areas are taken into consideration, resulting in a differential subsidy policy.

In terms of greenhouse gas emission, coal mine production safety and security of energy supply, the social benefits derived from the production of 1 m^3 CBM can be expressed as equal to 0.035 USD. Thus we suggest that the Government, provides a subsidy of 0.035 USD per cubic metre of CBM to Fengfeng, Liupanshui, Zhina and other CBM prospects (but not for power generation), to improve the development of CBM resources in these prospects.

7.5.3.3. CBM Price

From the foreign experiences we know that the price policy has a great positive effect on the development of gas industry. In China, lots of citizens still enjoy fiscal subsidy, and the price of gas extracted in coalmine area as welfare provided to workers is low, but all these are unfavorable for the development of CBM industry. The country needs to set reasonable gas price policy and relevant departments of local governments should loose the control of the price of gas as soon as possible. This will ensure the competitive ability of CBM to nature gas, coal gas, blue gas, and create a favorable environment for the CBM industry.

7.5.3.4. Arrangement of Purchasing Emission Reduction Quota of Greenhouse Gases

CDM is a kind of mechanism to carry out the arrangement stated by the Kyoto Protocol for developed countries to realize emission reduction agreement outside their countries. Its core is to allow developed and developing countries to implement transference and profit of CERs on the basis of investment projects. Development and utilization of CBM is the important domain for implementing CDM mechanism. It is necessary for the state to strengthen propaganda and service of this mechanism, so as to provide more opportunity to get fund and technology. Moreover, it is also necessary for the state to set up even strict laws and regulations, find methane emission reduction fund, promulgate allowance policy about methane emission reduction and penalty system about emission standard, so as to encourage companies to develop and utilize CBM.

7.5.4. Enhancing the Construction of Gas (CBM) Basic Pipe Network, And Implementing the Licensed Access to Pipe Network

7.5.4.1. Enhancing the Construction of Gas (CBM) Basic Pipe Network

Prediction of market demand of CBM prospects shows that CBM local demand is not sufficient for large-scaled commercial development and transporting CBM to outside by pipeline is the main way to solve this problem. Effected by the low economic benefits of CBM development, if CBM companies construct the long-distance pipeline of their own, the risk of CBM development increases and companies in CBM development would be discouraged. CBM and natural gas could be simutaneously transported and utilized, and have common market and consumers. Moreover, the location of CBM and natural gas can be complement to each other. So, when planning the construction of natural gas long-distance pipelines, the state should fully think of the characteristic of mixed transportation and distribution of CBM resources, arrange the natural gas long-distance pipelines to be closer to CBM production bases by any possibility, obligate enough capacity for future CBM pipeline to merge into, and lower the investment of pipeline construction at the early development stage of CBM industry. Similarly, construction of CBM long-distance pipelines should be included in national infrastructure planning, and invest, periodically, infrastructure funds in the area to gradually set up Chinese CBM (natural gas) long-distance pipeline network.

7.5.4.2. Implementing the Admittance Regime of Pipe Network

Admittance regime of pipe network also called third-party access refers to a kind of third-party right to pay to use transportation and relative services of pipeline network companies to transport its CBM. Pipeline network includes natural gas long-distance pipeline and local pipeline network. For CBM companies, transportation ability of natural gas long-distance pipeline is needed. There are certain conditions for natural gas long-distance pipeline implemented by the admittance regime: pipeline companies are independent legal entities, who have well-developed market, marginal pipeline transportation ability; there are enough CBM suppliers willing to use this service instead of constructing the pipelines by theirselves; there is possibility to connect pipelines. However, China does not have the condition, so it is difficult to impose admittance regime recently. Along with the development of CBM and natural gas industries, there will be more and more suppliers who need the pipeline to sell their CBM (natural gas). So, as a transitional measure, negotiated third-party admittance regime should be considered. Pipeline companies and consignors together determine admittance. What the government needs to do is to require transportation traders to publish their pipeline transportation and relative services. The third-party admittance regime could be implemented later.

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Annex

Annex 1 Basic Data and Parameter Tables

Annexed Table 1 Geological parameters of the CBM belts in China

No.	CBM belt	Coal-forming age	Main Coal Rank	Burial Depth (m)	Gas Saturation (%)	Gas Content (m^3/t)	Resources Density $(10^6m^3/km^2)$	CBM Resources (10^9m^3)
1	Sanjiang-Mulinghe I_{01}	K1		<1,000		3.46	24	224.35
		K1	FM/JM	1,000~1,500		8.28		
				1,500~2,000		9.98		
2	Yanbian I_{02}	K1		<1,000		3.46	2	1.33
3	Hunjiang-Liaoyang I_{03}	K1		<1,000		3.46	44	70.33
		C-P				13.2		
		C-P	JM/SM/WY	1,000~1,500	85	14.31		
				1,500~2,000	85	15		
4	Fushun I_{04}	R3		<1,000		9.23	7	4.46
		R3	CY	1,000~1,500		9.23		
5	West Liaoning I_{05}	K1		<1,000		5.4	15	41.24
		C-P				5.84		
		K1	CY/QM	1,000~1,500		5.62		
		C-P	FM/JM/PM	1,500~2,000	80	8.93		
6	East Songliao Basin I_{06}	K1		<1,000		3.46	2	3.52
		K1	CY	1,000~1,500		3.87		
7	Southwest Songliao Basin I_{07}	K1		<1,000		3.46	2	2.69
8	The eastern of north Hebei II_{01}	J1-2		<1,000		4.36	12	8.01
		C-P				5.84		
		J3	QM	1,000~1,500		6.04		
				1,500~2,000		6.8		
		C-P	QM/FM/JM	1,000~1,500	80	7.66		
9	Beijing-Tangshang II_{02}	C-P		<1,000		5.84	115	109.21
		C-P	QM/WY	1,000~1,500	80	9.03		
				1,500~2,000	80	9.81		
10	East Taihang Mountain II_{03}	C-P		<1,000		9.13	118	442.81
			QM/FM/WY	1,000~1,500	85	15.98		
				1,500~2,000	85	16.55		

Continue

No.	CBM belt	Coal-forming age	Main Coal Rank	Burial Depth (m)	Gas Saturation (%)	Gas Content (m^3/t)	Resources Density ($10^6 m^3/km^2$)	CBM Resources ($10^9 m^3$)
11	Central Hebei Plain II_{04}	C-P		<1,000			115	430.8
		C-P	QM/FM	1,000~1,500		10.79		
				1,500~2,000		10.79		
12	North Henan and northwest Shandong II_{05}	C-P		<1,000			26	250.07
		C-P	QM/WY	1,000~1,500	60	6.22		
				1,500~2,000	60	6.65		
13	West Henan II_{08}	C-P		<1,000		5.44	131	559.84
		C-P	JM/SM/PM	1,000~1,500	80	13.43		
				1,500~2,000	80	13.67		
14	East Henan II_{09}	C-P		<1,000		6.85	115	400.23
		C-P	SM/PM/WY	1,000~1,500	85	18.72		
				1,500~2,000	85	19.33		
15	Xuhuai II_{10}	C-P		<1,000		6.27	5	339.91
		C-P	QM/FM/JM	1,000~1,500	85	7.76		
				1,500~2,000	85	8.26		
16	Huainan II_{11}	C-P		<1,000		6.27	134	348.57
		C-P	QM/JM/FM	1,000~1,500	85	7.76		
				1,500~2,000	85	8.26		
17	Southeast Hubei and north Jiangxi III_{01}	P2		<1,000		15.12	6	5.6
18	lower Yangtze river III_{02}	P2		<1,000		7.01	11	10.25
		P2	SM/PM/WY	1,000~1,500	75	14.5		
19	Jiangsu, Zhejiang and Anhui III_{03}	P2		<1,000		7.01	10	18.15
		P2	FM/JM/PM	1,000~1,500	75	8.6		
20	Jiangxi and Zhejiang III_{04}	P1		<1,000		7.01	5	2.87
		P1	PM/WY	1,000~1,500	75	13.1		
21	Pingle III_{05}	T3		<1,000		7.96	10	25.89
		P2				15.12		
		P2	SM/PM/WY	1,000~1,500		15.22		

Continue

No.	CBM belt	Coal-forming age	Main Coal Rank	Burial Depth (m)	Gas Saturation (%)	Gas Content (m^3/t)	Resources Density ($10^6m^3/km^2$)	CBM Resources (10^9m^3)
22	Central Hunan III_{06}	P2		<1,000		13.79	30	42.39
		C1				17.51		
		P2	SM/PM/WY	1,000~1,500		12.18		
		C1	PM/WY			21.44		
23	South Hunan III_{07}	P2		<1,000		19.92	21	37.26
		P2	WY	1,000~1,500		21.61		
24	North and central Guangxi III_{08}	P2		<1,000		4.87	15	13.69
		C1				4.87		
		P2	JM/SM/PM	1,000~1,500	80	10		
		C1	JM/SM/PM	1,000~1,500	80	12.76		
25	Biogas, not divided			<1,000				
26	The western of north Hebei V_{01}	J1-2		<1,000		4.36	9	8.8
		J1-2	CY/QM	1,000~1,500		6.43		
27	Daning V02	C-P		<1,000		5.87	138	265.3
		C-P	QM/FM/JM	1,000~1,500	80	9.64		
				1,500~2,000	80	10.14		
28	Qinshui V_{03}	C-P		<1,000		16.13	201	5,515.78
		C-P	SM/PM/WY	1,000~1,500	95	21.39		
				1,500~2,000	95	22.06		
29	Huoxi V_{04}	C-P		<1,000		16.13	183	735.55
		C-P	FM/JM/SM	1,000~1,500	95	21.39		
				1,500~2,000	95	22.06		
30	Eastern margin of the Ordos Basin V_{05}	C-P		<1,000		6.72	122	1,996.23
		C-P	FM/JM/SM	1,000~1,500	85	10.96		
				1,500~2,000	85	11.4		
31	Weibei V_{06}	C-P		<1,000		7.87	94	701.1
		C-P	SM/PM/WY	1,000~1,500	85	18.31		
				1,500~2,000	85	18.84		

Continue

No.	CBM belt	Coal-forming age	Main Coal Rank	Burial Depth (m)	Gas Saturation (%)	Gas Content (m^3/t)	Resources Density ($10^6m^3/km^2$)	CBM Resources (10^9m^3)
32	North Ordos Basin V_{07}			<1,000			109	5,582.56
		J1-2	CY/QM	1,000~1,500		5.4		
				1,500~2,000		8.1		
		C-P	CY/QM	1,000~1,500		4.14		
				1,500~2,000		6.21		
33	West Ordos Basin V_{08}	J1-2		<1,000			63	1,273.21
		J1-2	CY	1,000~1,500		4.88		
				1,500~2,000		5.32		
34	Zhuo-He V_{09}	J1-2		<1,000		10.4	179	782.91
		C-P				4.67		
		C-P	JM/SM/PM	1,000~1,500	80	11.84		
				1,500~2,000	80	12.5		
35	North Shaanxi V_{10}	J1-2		<1,000			33	373.28
		J1-2	CY/QM	1,000~1,500		6.29		
36	Huanglong V_{11}	J1-2		<1,000			6	14.28
		J1-2	CY	1,000~1,500		4.14		
				1,500~2,000		4.97		
37	Huaying-shan VI_{01}	T3		<1,000		7.96	25	62.34
		P2				9.59		
		P2	JM/SM/PM	1,000~1,500	80	10.96		
38	Yongrong VI_{02}	T3		<1,000		7.96	24	77.3
		P2				9.59		
		P2	SM/WY	1,000~1,500	85	15.7		
39	Yalian VI_{03}	P2		<1,000		7.96	0.06	21.19
		P2	JM	1,000~1,500	70	8.41		
40	South Sichuan and north Guizhou VI_{04}	T3		<1,000		7.96	33	1,038.18
		P2				12.43		
		T3	SM	1,000~1,500	70	10.3		
		P2	WY	1,000~1,500	75	13.5		
				1,500~2,000	80	15.96		
41	Guiyang VI_{05}	P2		<1,000		5.17	17	94.05
		P2	SM/PM/WY	1,000~1,500	75	14.32		
				1,500~2,000	80	15.44		

Continue

No.	CBM belt	Coal-forming age	Main Coal Rank	Burial Depth (m)	Gas Saturation (%)	Gas Content (m^3/t)	Resources Density ($10^6m^3/km^2$)	CBM Resources (10^9m^3)
42	Liupanshui VI_{06}	P2		<1,000		7.19	170	1,509.43
		P2	JM/PM/WY	1,000~1,500		13.81		
				1,500~2,000		16.66		
43	Dukou Chuxiong VI_{07}	T3		<1,000		7.96	10	26.13
		T3	SM/WY	1,000~1,500	75	13.6		
44	Turpan-Hami VII_{01}	J1-2		<1,000		4.08	151	2,625.9
		J1-2	CY/QM	1,000~1,500		5.98		
				1,500~2,000		7.68		
45	Santang-Naomaohu VII_{02}	J1-2		<1,000		4.08	31	334.55
		J1-2	CY/FM	1,000~1,500		6.41		
				1,500~2,000		7.21		
46	South Junggar VII_{03}	J1-2		<1,000		4.36	53	347.25
		J1-2	CY/QM	1,000~1,500		5.86		
		J1-2	CY/QM	1,500~2,000		7.53		
47	North Junggar VII_{05}	J1-2		<1,000		4.36	23	503.02
		J1-2	CY/QM	1,000~1,500		5.49		
				1,500~2,000		7.06		
48	Ili VII_{06}	J1-2		<1,000		4.08	121	1219.19
		J1-2	CY/QM	1,000~1,500		5.82		
				1,500~2,000		7.48		
49	Yourdusi VII_{07}	J1-2		<1,000		4.36	10	47.63
		J1-2	QM	1,000~1,500		6.96		
				1,500~2,000		7.83		
50	Yanqi VII_{08}	J1-2		<1,000		4.36	30	345.55
		J1-2	QM	1,000~1,500		6.87		
				1,500~2,000		7.73		
51	Inner Mongolia, Gansu and Ningxia $VIII_{01}$	J1-2		<1,000		3.44	57	90.38
		C-P				4.67		
		J1-2	CY/QM	1,000~1,500		5.83		
		C-P	SM/PM/WY	1,000~1,500	50	8.97		
				1,500~2,000	65	11.79		

Continue

No.	CBM belt	Coal-forming age	Main Coal Rank	Burial Depth (m)	Gas Saturation (%)	Gas Content (m^3/t)	Resources Density ($10^6m^3/km^2$)	CBM Resources (10^9m^3)
52	Xining-Lanzhou $VIII_{02}$	J1-2		<1,000		4.16	18	10.2
		J1-2	CY/FM	1,000~1,500		6.58		
				1,500~2,000		7.41		
53	Hexi Corridor $VIII_{03}$	J1-2		<1,000		4.16	47	191.91
		C-P				4.67		
		J1-2	PM/SM/WY	1,000~1,500	50	9.74		
				1,500~2,000	65	12.81		
		C-P	QM/JM	1,000~1,500	60	5.35		
				1,500~2,000	65	6.35		
54	Nouth Qaidam $VIII_{04}$	J1-2		<1,000		4.16	33	54.46
		C-P				4.67		
		J1-2	CY/QM	1,000~1,500		5.22		
				1,500~2,000		6.71		
		C-P	JM	1,000~1,500	65	9.59		
55	East Tarim $VIII_{05}$	J1-2		<1,000		4.08	134	521.77
		J1-2	QM	1,000~1,500		6.87		
		J1-2	QM	1,500~2,000		7.73		
56	No data VIIII	J1-2						
57	Taiwan X			<1,000				

Annexed Table 2 Geological parameters of the Chinese CBM prospects

NO.	Prospect	CBM-bearing Area (km^2)	Coal Rank	Burial Depth (m)	Coal Reservior Pressure (MPa)	Coal Reservior Thickness (m)	Permeability ($\times10^{-3}\mu m^2$)	Gas Content (m^3/t)	Porosity (%)
1	Daqingshan	32.63	QM-SM		5~15	10		16.4	5.65
2	Xuanxia	297.81	CY-JM		5~10	10		15	4.9
3	Xinglong	68.18	QM-WY		5~22	8.65		15	5.16
4	Kailuan	12.25	JM-WY	700~950	5.82	15~20	0.03~0.25	10.2	0.5
5	Jiyu	1,382.79	QM-WY	700~950	12	10~20	0.03~0.25	5	0.5
6	Liujiang	63.94	QM-FM	700~950	16	10	0.03~0.25	15	0.5
7	Dacheng	3,333.55	QM-WY	1,120~1,300	11.5	10~28	0.084	8	3.7
8	Jiaozuo	750.45	PM-WY	500~1,500	0.88~11	0.36~12.69	1.776~2.96	20.1	7~12
9	Anyang-Hebi	607.53	SM-WY	1,000~2,000	6.04~9.14	3.49~22.2	0.178	14.4	9~14
10	Fengfeng	665.76	SM-WY	1,000~2,000	1.75~6.23	4.5~11.5	0.792~1.79	8	7~14
11	Lincheng	121.47	WY	1,000~2,000		9~15	0.159~0.315	8	7~14
12	Lingshan	50.28	JM-PM	1,000~2,000		9~15	0.159~0.315	10	7~14
13	Yangquan	5,442.25	FM-WY	550~650	2.06~6.25	13	0.08~0.103	13.3	1.41~8.67
14	Heshun-Zuoquan	4,646.69	FM-JM	1,309.35	3.84	5~17	0.5~0.987	10	1.15~7.69
15	Lu’an	3,265.27	QM-JM	800~	1.54~4.53	15	1.97	9.9	2.88
16	Jincheng	1,348.44	QM-JM	700	2.77~4.76	5~6	0.98	14.1	3.38~9.89
17	Huodong	6,568.24	QM-SM	674.37	3.84	5~17	0.987	4.3	1.15~7.69
18	Taiyuan Xishan	1,123.65	QM-FM	674.37	3.84	5~17	0.987	5.7	1.15~7.69
19	Huozhou	1,729.88	FM-WY	674.37	3.84	15	0.987	5	1.15~7.69
20	Ningwu	849.5	PM-WY	100~1,500	8.7	14~24	0.3-2	6	8~15
21	Fugu	3,049.3	JM-PM	<1,500		2~28.5	3.168	5	6.5
22	Liulin	3,338.2	CY-FM	366.98	3.7~4.5	5~15	1.0~1.13	9.7	5~6
23	Sanjiaobei	1920.57	FM-JM	500~1,200	4	8~17.5	0.15~11.6	8.7	4.6
24	Xiangning	2,117.95	FM-SM	600~1,500	3	8.0~12.49	0.1~12	5	1.67~4.81
25	Hancheng	4,784.29	JM-WY	300~900	7.6~8.5	8.93	1.93~3.01	11.8	5.4
26	Tongchuan	4,309.85	QM-WY	400~1,400	7.5~8.5	6.89	0.141~0.859	6	3
27	Ordos Basin	53,888.1	QM-FM	200~700	5	8	0.5~8	3~14.2	8.32
28	Zhuozishan	49.82	QM-WY	500~800		2.17~15.95	0.1~2.5	5.6	7.5~15

Continue

NO.	Prospect	CBM-bearing Area (km^2)	Coal Rank	Burial Depth (m)	Coal Reservior Pressure (MPa)	Coal Reservior Thickness (m)	Permeability ($\times 10^{-3} \mu m^2$)	Gas Content (m^3/t)	Porosity (%)
29	Shizuishan	57.95	PM-WY	600~1,300		13.5	1.49~16.29	6.1	0.1~3.6
30	Hulusitai	69.13	QM-WY			24.81	0.5	8	2.5~7.5
31	Rujigou	23.54	WY			20.9	0.5	13.4	4.06
32	Leping	38	WY	800~1,200	8.5~8.9	2	<3.34	10.7	12.95
33	Fengcheng	722.3	QM-MY	965	3.4~8.9	2.4	2.45	17.9	1.7~8
34	Lianshao	389.15	FM-WY		2.2~6.9	9.19~15.3	0.73~1.28	9.6	1~5
35	Tianfu	220.42	JM	1,000	1~14	7.96	<0.35	15.6	
36	Libixia	222.68	FM-JM			5.61~12.95		9.4	
37	Songzao	293.94	WY			4.98~10.69	0.301	27.1	1~5
38	Northwest Guizhou	529.52	JM-PM	<1,500		27.1~34.7	<0.1	8	
39	Guishan	86.74	FM-WY	200~1,500	0.46~1.32	20~40	Low	7.7	0.02
40	Enhong	685.21	JM-SM	200~1,500	2.9~5.9	18.04	High	9.2	0.02
41	Xuanwei	8,476.63	FM-JM	200~1,500	0.46~1.32	20~40	Low	9.7	0.02
42	Liupanshui	4,592.38	QM-WY	200~1,500	0.46~1.32	20~40	Low	12	0.02
43	Xingyi	2,550.25	WY	200~1,500	0.46~1.32	20~41		6.5	0.02
44	Zhina	4,374.38	WY	200~1,500	0.46~1.32	20~42		12	0.02
45	Guiyang	3,158.38	JM-PM					8	
46	Hongmao	133.21	WY					12	
47	Luocheng	46.78	WY					14	
48	Heshan	137.51	PM					14.7	
49	Baiyanghe	169.98	CY-FM	400~2,000		139.2	High	6.2	High
50	Aiweiergou	50.02	QM-SM					7	
51	Huhehu Depression		CY-QM						
52	Huolinhe	380	HM-CY					2.5	
53	Hegang	309.53	CY-QM	600~1,000	2.24~5	2~10	0.04~0.4	7	0.2~0.4
54	Jixi	1,841.56	QM-JM	700~900		2~10	0.2~1.4	6	0.04~0.1
55	Shuangya-shan	239	CY-QM	600~900	4.1	9~34	1.15~7.18	9.4	0.03~0.5
56	Boli	537.72	QM-WY	800	4.4~9	9~43		6	0.044~0.064

Continue

NO.	Prospect	CBM-bearing Area (km^2)	Coal Rank	Burial Depth (m)	Coal Reservior Pressure (MPa)	Coal Reservior Thickness (m)	Permeability ($\times10^{-3}\mu m^2$)	Gas Content (m^3/t)	Porosity (%)
57	Hongyang	426.27	QM-WY	800	5.1	40~50	0.16	16.2	0.1~0.4
58	Fuxin	139.87	CY-QM	800	6.7	60~80	0.3~0.6	4.9	0.2~0.4
59	Tiefa	84.61	CY-QM	850	4	30~40	0.1~1.507	6.5	0.1~0.4
60	Huainan	1,373.74	QM-SM	600~800	4.2~6	30~40	0.1~2.8	6.8	
61	Huaibei	450	QM-WY	600~900		30~40	0.5~3.2	7.5	
62	Zhongliang-shan	255.95	JM			12	0.01~0.02	17	
63	Wupu	2117.95	FM-JM	1200~1500		5~15	0.06~0.07	9	
64	Gufoshan	417.48	JM-WY					17.7	
65	Nantong	146.24	FM-WY			0.5~9.93		15	
66	Luoguan-shan	340.92	JM-SM					18.5	
67	Pingxiang	9.99	JM-WY	800~1200		0.6~4.57	0.1~0.34	20	
68	Furong	908.91	WY			4.5		15.3	
69	Middle Huayingshan	421.07	FM-PM					12.2	
70	North Huayingshan	161.56	QM-JM					10.2	
71	Yangqiao-Yuancun	221.58	WY			0.6~4.57		12.3	
72	Nanwu	45.59	JM-PM				0.01~0.37	10	
73	Qianbei	11372.54	SM-WY					7	
74	Pubai	1571.48	JM-SM	500~2000		5~7	0.064	6	
75	Maliantan	189.65	WY					9.4	
76	Zhenxiong	2935.25	WY					10	
77	Chenghe	1941.22	SM-PM	500~700		2~8	0.1~0.9	8.4	
78	Junlian	983.57	WY					10.7	
79	Guxu	916.06	WY					9.7	
80	Qingshan-ling	223.94	JM-WY					8.6	
81	Zhongshan	131.75	QM-SM					8.7	
82	Hetianci	71.71	JM-PM					8.1	
83	Emeishan	88.87	QM-JM					8.6	
84	Xishan	155.87	JM-WY					11.5	
85	Weizhou	578.43	QM-WY					5.8	

Annexed Table 3 Predicted production of the Chinese CBM prospects with vertical wells

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Prospect	Daqing-shan	Xuanxia	Xinglong	Kailuan	Jiyu	Liujiang	Dacheng	Jiaozuo	Anyang-Hebi	Fengfeng	Lincheng	Lingshan	Yangquan	Heshun-Zuoquan	Lu'an	Jincheng
Depth (m)	800	850	900	810	890	910	1140	1310	1510	1502	1010	1015	610	1010	810	710
1*	764.63	783.90	1,140.32	1,355.73	1,787.02	1,689.10	1,660.24	2,283.09	1,720.35	981.01	2,142.36	2,680.05	2,442.67	1,477.24	1,725.33	2,108.07
2	2,492.23	2,433.72	3,080.46	1,989.41	2,207.51	2,287.41	2,050.62	2,540.16	2,618.71	2,420.31	2,640.59	2,892.09	3,262.05	1,663.34	2,542.76	2,698.02
3	2,722.83	2,602.29	3138.03	2,354.83	2,295.63	2,398.03	2,730.24	2,584.97	2,603.45	2,434.23	2,652.66	2,871.34	3235.62	1,591.12	2,554.66	2,733.26
4	2,471.06	2,335.74	2,792.57	2,411.08	2,285.49	2,275.07	2,700.27	2,573.73	2,290.24	2,236.22	2,001.73	2,309.44	2,139.68	1,476.77	1,998.65	2,474.27
5	2,217.52	2,086.62	2,491.08	2,309.42	2,210.84	2,093.90	2,510.04	2,535.61	2,063.63	2,007.92	1,739.05	2,046.32	1,780.00	1,361.71	1,754.59	2,232.37
6	1,978.62	1,854.29	2,200.11	2,210.25	2,075.80	1,928.32	2,290.79	2,477.27	1,881.32	1,751.46	1,522.88	1,816.71	1,488.23	1,256.21	1,559.69	2,016.95
7	1,758.70	1,642.28	1,944.45	2,140.57	1,947.02	1,783.08	2,110.49	2,407.41	1,718.19	1,577.55	1,346.33	1,618.46	1,253.51	1,159.49	1,411.31	1,738.30
8	1,562.09	1,454.80	1,729.10	2,030.48	1,826.26	1,650.56	1,930.29	2,330.21	1,574.23	1,430.45	1,202.61	1,448.82	1,066.26	1,072.53	1,294.45	1,542.37
9	1,395.31	1,296.76	1,547.33	1,900.24	1,716.47	1,532.19	1,720.56	2,248.60	1,447.85	1,305.82	1,086.03	1,305.22	918.27	995.01	1,202.58	1,371.87
10	1,253.99	1,163.31	1,391.82	1,780.42	1,617.80	1,426.45	1,520.47	2,164.16	1,338.44	1,201.61	991.35	1,181.09	800.14	925.95	1,131.61	1,224.78
11	1,134.14	1,050.56	1,258.91	1,660.05	1,528.50	1,331.03	1,400.24	2,080.03	1,242.18	1,113.98	914.26	1,076.55	705.05	864.81	1,077.90	1,091.78
12	1,031.39	954.02	1,146.44	1,560.57	1,448.95	1,244.76	1,280.86	1,996.97	1,158.82	1,040.29	851.21	987.65	628.01	810.94	1,037.53	975.64
13	942.44	870.60	1,050.85	1,480.02	1,350.25	1,166.83	1,180.47	1,913.56	1,086.26	978.44	799.47	911.83	565.11	763.63	951.52	913.70
14	865.62	798.97	969.23	1,370.45	1,220.47	1,098.90	1,090.27	1,832.37	1,023.30	926.56	756.86	846.99	513.48	722.35	959.33	872.37
15	799.42	737.36	899.08	1,270.68	1,110.15	1,038.45	1,010.14	1,753.66	968.06	883.14	721.54	791.41	470.63	686.41	916.35	839.33
16	742.17	684.20	838.24	1,200.02	1,010.04	1,010.04	910.45	1,676.74	920.38	846.97	692.11	743.70	435.08	655.24	872.34	792.11
17	692.70	638.15	785.14	1,040.27	900.43	940.33	840.13	1,601.94	878.89	817.00	667.43	702.96	405.71	628.29	847.20	766.39
18	649.07	598.08	738.66	950.54	820.75	880.56	770.24	1,529.71	842.68	792.34	646.59	667.53	381.32	604.98	832.54	713.68
19	610.98	563.00	697.89	840.05	732.65	830.89	740.63	1,460.28	810.98	772.14	628.82	636.80	360.84	584.99	811.24	711.24
20	577.36	532.07	662.02	770.32	615.59	750.61	700.01	1393.83	783.19	755.66	613.52	610.08	343.50	567.85	823.69	687.68

*The numbers in the first line refer to year; the production is the average single-well day output in certain year with controlled area per well of 0.1 km^2, and the unit is m^3/d.

Continue

No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Prospect	Huodong	Taiyuan Xishan	Huozhou	Ningwu	Fugu	Liulin	Sanjiaobei	Xiangning	Hancheng	Tongchuan	Ordos Basin Jura	Zhuozi-shan	Shizui-Shan	Hulusitai	Rujigou	Leping
Depth (m)	665	665	665	800	920	376	915	810	908	907	708	715	913	924	820	905
1	1,866.32	1,483.85	1,765.38	1,242.37	676.34	667.20	843.15	1,795.32	1,290.27	1,377.50	1,247.83	652.61	891.83	316.71	589.78	759.79
2	2,402.65	2,462.35	2,521.86	1,868.36	2,059.92	1,663.43	2,062.85	1,737.92	2,434.37	2,200.94	2,436.41	2,041.24	2,200.28	1,434.26	2,000.19	1,543.93
3	2,536.35	2,529.80	2,530.01	2,705.23	2,139.15	1,697.69	2,103.85	1,418.94	2,295.56	1,916.79	2,062.18	2,111.23	2,212.93	1,987.53	2,277.29	1,467.14
4	2,394.37	2,341.39	2,281.97	2,957.04	1,986.98	1,575.99	1,914.33	1,259.86	2,062.05	1,670.04	1,677.45	1,962.46	2,032.93	2,062.68	2,246.32	1,325.18
5	2,159.64	2,107.13	2,014.55	2,924.89	1,796.29	1,433.11	1,702.11	1,163.53	1,837.68	1,460.60	1,389.91	1,777.42	1,825.38	1,979.62	2,085.38	1,189.63
6	1,883.61	1,886.22	1,773.03	2,615.24	1,572.58	1,298.89	1,512.10	1,106.49	1,644.15	1,276.07	1,146.88	1,561.24	1,592.24	1,860.77	1,940.95	1,075.95
7	1,657.47	1,690.65	1,565.73	2,326.33	1,419.93	1,156.76	1,318.97	1,069.96	1,455.08	1,118.39	1,012.04	1,414.45	1,434.14	1,734.36	1,794.93	972.00
8	1,473.07	1,521.80	1,393.01	2,098.24	1,289.43	1,063.03	1,194.13	1,041.99	1,338.91	983.62	912.46	1,291.23	1,300.41	1,613.34	1,661.30	912.83
9	1,323.27	1,379.60	1,250.24	1,837.00	1,180.33	986.07	1,090.42	1,015.47	1,247.99	869.41	840.27	1,189.34	1,187.11	1,497.05	1,539.28	870.53
10	1,201.06	1,259.13	1,131.68	1,678.65	1,089.54	924.12	1,004.87	986.94	1,178.02	773.83	789.86	1,106.20	1,092.37	1,389.39	1,427.98	841.64
11	1,099.91	1,156.45	1,032.52	1,492.42	1,014.18	875.28	934.32	955.27	1,125.05	694.05	755.93	1,039.19	1,012.71	1,293.10	1,328.72	823.05
12	1,015.03	1,068.86	949.04	1,351.04	952.34	837.30	876.24	921.16	1,085.49	627.78	734.43	985.93	945.72	1,207.10	1,240.80	811.57
13	943.37	993.98	878.39	1,262.50	901.90	808.28	828.55	887.77	1,056.39	572.49	722.19	944.31	889.49	1,129.33	1,162.35	804.73
14	882.68	929.65	818.23	1,196.34	861.25	786.54	789.50	852.52	1,035.32	525.90	716.65	912.30	842.32	1,059.42	1,092.48	800.33
15	830.85	873.96	766.63	1,118.27	828.92	770.61	757.78	815.13	1,020.35	486.36	716.40	888.19	802.86	996.84	1,030.35	796.66
16	786.10	825.51	721.79	1,078.24	803.56	759.30	732.38	776.51	1,009.74	454.49	719.68	870.59	769.98	941.19	975.20	792.49
17	747.22	783.25	682.54	1,037.01	784.03	751.68	712.35	737.78	1,002.13	427.42	725.36	858.39	742.72	891.50	926.15	787.02
18	713.36	746.36	647.92	1,021.04	769.31	746.95	696.75	699.48	996.24	403.84	732.91	850.49	720.31	846.87	882.43	779.86
19	683.77	714.01	617.27	1,001.78	758.58	744.33	684.81	661.96	991.15	383.28	741.39	845.95	701.95	806.73	843.48	770.80
20	657.74	685.47	590.10	920.55	751.16	743.21	675.91	625.48	986.25	365.20	750.20	844.09	686.97	770.55	808.73	759.88

Continue

No.	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Prospect	Feng-cheng	Lianshao	Tianfu	Libixia	Songzao	Northwest Guizhou	Guishan	Enhong	Xuanwei	Liupan-shui	Xingyi	Zhina	Guiyang	Hongmao	Luocheng	Heshan
Depth (m)	970	815	1010	1010	1010	1210	800	900	700	1000	1100	950	700	850	850	900
1	947.47	1,010.34	1,556.65	1,030.47	1,000.70	545.85	610.64	1,082.10	554.59	757.99	675.23	820.43	673.34	749.84	569.13	537.94
2	1,900.43	2,301.91	2,319.95	1,774.39	1,687.21	1,463.05	1,641.53	2,453.29	1,604.88	2,118.56	1,822.13	2,097.06	1,797.33	1,971.39	1,532.95	1,698.83
3	1,766.73	2,348.15	1,836.53	1,619.29	1,536.88	1,509.37	1,758.44	2,471.00	1,859.12	2,411.04	2,021.29	2,328.00	2,009.80	2,260.13	1,842.43	1,825.96
4	1,590.92	2,218.31	1,481.79	1,410.73	1,326.37	1,384.71	1,666.59	2,293.93	1,771.50	2,289.81	1,921.20	2,194.32	1,923.32	2,183.95	1,809.01	1,643.14
5	1,435.23	2,007.02	1,194.23	1,194.63	1,174.48	1,253.68	1,554.79	2,091.44	1,669.98	2,209.83	1,831.36	2,025.04	1,788.90	2,046.67	1,710.71	1,468.97
6	1,294.37	1,841.32	980.52	1,003.92	1,024.37	1,154.44	1,396.71	1,923.48	1,535.39	2,001.49	1,648.27	1,852.58	1,640.05	1,897.66	1,593.43	1,306.26
7	1,220.77	1,688.74	816.28	845.67	892.87	1,082.78	1,229.31	1,756.25	1,369.90	1,777.89	1,455.70	1,688.10	1,497.77	1,773.34	1,475.17	1,157.81
8	1,173.87	1,548.83	687.95	716.58	781.33	1,003.58	1,068.22	1,593.84	1,209.09	1,563.65	1,268.63	1,546.43	1,378.44	1,641.97	1,360.59	1,025.91
9	1,146.26	1,425.86	589.32	611.49	688.35	921.31	923.71	1,445.31	1,059.95	1,363.00	1,099.86	1,417.07	1,265.55	1,509.35	1,253.81	914.53
10	1,131.39	1,317.05	511.39	526.10	614.14	844.51	795.80	1,311.82	927.35	1,182.84	949.34	1,297.96	1,161.09	1,386.85	1,155.62	820.47
11	1,122.93	1,220.54	448.70	456.41	557.62	773.90	685.83	1,191.95	805.59	1,024.00	819.15	1,190.29	1064.96	1,275.37	1,066.75	740.94
12	1,116.63	1,135.90	398.37	399.61	511.58	709.20	591.17	1,084.85	698.31	886.55	706.71	1,093.43	977.32	1,173.47	986.94	672.91
13	1,108.98	1,061.73	357.95	352.97	472.53	650.60	511.27	989.54	605.01	767.38	610.01	1,006.82	897.95	1,080.57	915.56	614.13
14	1,097.85	996.55	324.36	314.65	438.44	597.52	443.52	905.09	524.72	664.69	526.92	929.69	826.44	996.41	851.75	563.52
15	1,082.19	939.37	296.99	282.62	407.57	549.97	385.55	830.64	456.01	576.05	455.35	861.27	762.15	919.75	794.86	519.97
16	1,061.91	889.24	273.90	255.79	379.38	510.94	336.70	765.04	397.02	499.47	393.80	800.78	704.94	850.44	744.01	482.37
17	1,037.49	845.29	254.60	233.11	353.74	475.10	295.02	707.12	346.49	433.47	340.98	747.66	653.06	787.91	698.49	449.94
18	1,009.51	806.82	238.18	213.78	330.90	443.76	259.61	655.92	303.24	376.51	295.62	703.29	606.85	731.47	657.64	421.39
19	978.68	773.18	224.05	197.14	310.67	416.70	229.42	609.81	266.24	327.36	256.61	663.88	565.29	680.60	620.95	396.51
20	945.65	743.80	211.77	182.74	292.96	393.93	203.66	569.34	234.56	284.91	223.24	628.74	528.43	634.91	587.91	374.58

Continue

No.	49	50	51	52	53	54	55	56	57	58	59	60	61			
Prospect	Baiyanghe	Aiweiergou	Huhehu Depression	Huolinhe	Hegang	Jixi	Shuang-Yashan	Boli	Hongyang	Fuxin	Tiefa	Huainan	Huaibei			
Depth (m)	800	820	850	950	800	750	800	800	820	820	870	700	750			
1	556.28	734.61	810.76	664.25	927.46	981.01	936.42	1,361.82	1,494.21	2,424.28	2,318.88	809.24	1,023.12			
2	2,035.00	1,948.92	1,983.67	1,802.48	2,269.14	2,420.31	2,310.30	2,427.15	1,845.56	3,102.72	2,967.82	2,531.13	2,758.46			
3	2,434.38	2,246.56	2,124.67	1,964.32	2,314.23	2,434.23	2,323.58	2,084.92	2,457.22	3,143.25	3,006.59	2,617.93	2,709.12			
4	2,312.20	2,161.97	1,968.50	1,805.20	2,105.77	2,236.22	2,134.57	1,794.10	2,430.24	2,845.41	2,721.70	2,433.45	2,260.93			
5	2,114.70	2,015.07	1,796.62	1,640.20	1,872.32	2,007.92	1,916.65	1,524.25	2,259.04	2,567.22	2,455.60	2,204.00	1,930.08			
6	1,915.52	1,859.46	1,642.62	1,481.24	1,663.31	1,751.46	1,671.85	1,307.71	2,061.71	2,319.50	2,218.65	1,935.94	1,652.86			
7	1,726.17	1,706.56	1,502.37	1,333.14	1,450.87	1,577.55	1,505.84	1,132.48	1,899.44	1,999.05	1,912.14	1,753.92	1,420.53			
8	1,550.54	1,563.74	1,369.27	1,200.74	1,313.55	1,430.45	1,365.43	986.85	1,737.26	1,773.72	1,696.61	1,601.13	1,228.67			
9	1,395.61	1,437.81	1,245.52	1,085.43	1,199.46	1,305.82	1,246.46	868.28	1,548.51	1,577.65	1,509.06	1,474.79	1,074.35			
10	1,262.21	1,324.94	1,132.78	985.67	1,105.36	1,201.61	1,146.99	772.65	1,368.42	1,408.50	1,347.26	1,371.69	949.53			
11	1,147.35	1,221.26	1,031.32	899.29	1,027.75	1,113.98	1,063.34	694.69	1,260.21	1,255.55	1,200.96	1,288.59	848.16			
12	1,048.39	1,127.01	941.08	824.01	963.87	1,040.29	993.01	630.15	1,152.77	1,121.98	1,073.20	1,222.55	764.22			
13	962.07	1,041.98	860.88	758.31	911.40	978.44	933.97	575.95	1,062.42	1,050.75	1,005.07	1,170.95	693.80			
14	886.43	965.75	789.64	701.08	868.45	926.56	884.44	530.46	981.24	1003.22	959.60	1,131.25	634.65			
15	820.51	897.57	726.36	651.17	833.56	883.14	843.00	492.14	909.12	965.23	923.26	1,101.35	584.76			
16	763.02	836.63	670.03	607.49	805.62	846.97	808.48	459.75	819.41	910.93	871.32	1,079.53	542.45			
17	712.80	785.07	620.19	569.21	783.59	817.00	779.86	432.15	756.11	881.35	843.03	1,064.40	506.42			
18	668.76	739.55	576.09	535.53	766.43	792.34	756.33	408.46	693.22	820.74	785.05	1,054.61	475.56			
19	629.96	698.73	536.84	505.73	753.30	772.14	737.04	387.89	666.57	817.92	782.36	1,048.98	448.90			
20	595.60	662.08	502.56	479.24	743.50	755.66	721.32	369.93	630.01	790.83	756.45	1,046.67	425.61			

Annexed Table 4 Predicted production of a part of the Chinese CBM prospects with multi-branch horizontal well

Prospect	Hancheng	Ningwu	Jincheng	Anyang-Hebi	Jiyu	Dacheng
Depth (m)	908	810	710	1510	820	1130
1*	19,586.14	19,834.46	21,302.68	18,511.91	15,902.63	17,468.49
2	25,582.20	33,402.54	26,003.82	31,567.43	21,623.12	29,028.13
3	25,502.35	35,512.47	31,402.73	31,625.63	29,806.25	29,922.74
4	23,108.46	34,501.78	32,016.79	27,741.14	30,815.01	29,359.47
5	19,206.78	31,611.07	26,503.18	22,612.08	26,138.35	24,203.56
6	15,225.69	26,172.64	24,321.08	18,389.67	18,304.16	19,612.51
7	10,806.19	19,402.45	18,603.05	14,412.72	14,021.83	15,712.64
8	9,266.13	14,525.57	14,505.78	11,315.42	9,708.19	13,301.36
9	8,233.74	11,300.49	11,512.04	8,248.05	6,946.2	10,711.07
10	7,336.56	9,043.48	9,420.45	6,812.54	5,353.67	8,905.26
11	6,560.26	7,538.79	8,295.59	5,924.36	4,813.11	7,812.74
12	5,887.75	6,809.64	7,534.35	5,201.42	4,328.59	6,423.05
13	5,302.16	6,161.08	6,908.04	4,942.45	4,010.07	5,321.07
14	4,790.43	5,584.91	6,385.14	4,846.95	3,923.15	5,211.38
15	4,341.53	5,071.71	5,942.84	4,421.45	3,315.06	5,236.42
16	3,945.61	4,614.16	5,557.94	4,234.87	3,234.61	4,915.51
17	3,594.62	4,204.85	5,218.61	3,721.45	3,123.61	4,628.92
18	3,282.53	3,838.85	4,919.26	3,312.04	2,912.63	4,607.53
19	3,004.27	3,510.09	4,652.37	2,921.45	2,905.36	4,500.35
20	2,755.50	3,214.28	4,411.63	2,721.57	2,817.62	4,483.26

**The numbers in the first line refer to year; the production is the average single-well day output in certain year with controlled area per well of 0.5 km^2, and the unit is m^3/d.

Annexed Table 5 Predicted current demand of the Chinese CBM prospects

No.	Prospect	Target market	Current Demand
1	Daqingshan	Zhangjiakou, Tangshan	1085
2	Xuanxia	Tangshan, Zhangjiakou	1085
3	Xinglong	Tangshan	840
4	Kailuan	Tangshan	840
5	Jiyu	Tangshan	840
6	Liujiang	Qinhuangdao	210
7	Dacheng	Langfang, Tangshan	1050
8	Jiaozuo	Jiaozuo, Jincheng, Zhengzhou	980
9	Anyang-Hebi	Anyang, Hebi	1050
10	Fengfeng	Xingtai, Handan, Shijiazhuang	1140
11	Lincheng	Xingtai, Handan, Shijiazhuang	1140
12	Lingshan	Baoding, Shijiazhuang	850
13	Yangquan	Yangquan, Taiyuan, Jinzhong	1480
14	Heshun-Zuoquan	Yangquan, Taiyuan, Jinzhong	1480
15	Lu’an	Changzhi, Jincheng, Jiaozuo, Zhengzhou	1170
16	Jincheng	Changzhi, Jincheng, Jiaozuo, Zhengzhou	1170
17	Huodong	Linfeng, Taiyuan	920
18	Taiyuan Xishan	Taiyuan	710
19	Huozhou	Huozhou, Linfen, Jinzhong	580
20	Ningwu	Datong, Suozhou	560
21	Fugu	Yulin, Lvliang	340
22	Liulin	Lvliang, Taiyuan	800
23	Sanjiaobei	Lviang, Taiyuan	800
24	Xiangning	Lvliang, Linfen	430
25	Hancheng	Hancheng, Xi’an, Weinan	1730
26	Tongchuan	Tongchuan, Xi’an	1640
27	Ordos Basin Jura	Ordos, Baotou	460
28	Zhuozishan	Wuhai, Shizuishan, Bayanzhuoer	370
29	Shizuishan	Wuhai, Shizuishan, Bayanzhuoer	370
30	Hulusitai	Wuhai, Shizuishan, Bayanzhuoer	370
31	Rujigou	Wuhai, Shizuishan, Bayanzhuoer	370
32	Leping	Leping, Nanchang, Jingdezheng, Yingtan	730
33	Fengcheng	Fengcheng, Nanchang, Xinyu, Yichun	1090
34	Lianshao	Loudi, Shaoyang, Changsha	830
35	Tianfu	Chongqing	1870
36	Libixia	Chongqing	1870
37	Songzao	Chongqing	1870
38	Northwest Guizhou	Chongqing, Zunyi, Guiyang	2600
39	Guishan	Kunming, Qujing, Liupanshui	930
40	Enhong	Kunming, Qujing, Liupanshui	930

Continue

No.	Prospect	Target market	Current Demand
41	Xuanwei	Kunming, Qujing, Liupanshui	930
42	Liupanshui	Liupanshui, Anshun, Guiyang	910
43	Xingyi	Liupanshui, Anshun, Guiyang	910
44	Zhina	Liupanshui, Anshun, Guiyang	910
45	Guiyang	Guiyang	560
46	Hongmao	Baise, Nanning	500
47	Luocheng	Hechi, Liuzhou, Guilin	560
48	Heshan	Laibin, Guilin, Nanning, Liuzhou	1150
49	Baiyanghe	Out sale through the West-East natural gas transmission pipeline	
50	Aiweiergou	Out sale through the West-East natural gas transmission pipeline	
51	Huhehu Depression	Hulunbeier	520
52	Huolinhe	Baotou, Huhehaote, Wulancha	830
53	Hegang	Hegang, Jimusi	440
54	Jixi	Jix, Qitaihe	400
55	Shuangyashan	Shuangyashan, Jiamusi	380
56	Boli	Qitaihe, Jixi	400
57	Hongyang	Shenyang, Liaoyang	1600
58	Fuxin	Fuxin	230
59	Tiefa	Tieling, Tiefa	250
60	Huainan	Huainan, Bengbu	630
61	Huaibei	Huaibei, Xuzhou, Suzhou	1110

Note: The unit of demand is 10^6 m^3.

Annexed Table 6 Annual production of the Chinese CBM prospects with vertical well

NO.	1	2	3	4	5	6	7	8
	Daqingshan	Xuanxia	Xinglong	Kailuan	Jiyu	Liujiang	Dacheng	Jiaozuo
1								
2	31.54	235.41	75.26	21.47	1,307.99	139.35	1,188.9	1,156.31
3	102.80	730.85	203.31	31.51	1,615.76	188.71	1,468.45	1,286.51
4	112.32	781.47	207.11	37.30	1,680.26	197.84	1,955.13	1,309.2
5	101.93	701.42	184.31	38.19	1,672.84	187.69	1,933.66	1,303.51
6	100.56	717.15	186.99	36.58	1,618.2	172.75	1,797.44	1,284.2
7	111.23	837.94	206.20	35.01	1,519.36	190.86	1,640.43	1,254.65
8	104.89	793.74	190.47	33.91	1,425.1	190.13	1,872.92	1,219.27
9	93.79	706.65	191.99	32.16	1,689.36	181.28	1,828.90	1,180.18
10	93.99	713.20	212.44	36.36	1,691.99	169.2	1,826.74	1,138.84
11	108.13	820.51	197.56	37.39	1,637.15	188.84	1,676.92	1,096.08
12	103.62	779.97	191.93	37.17	1,569.79	189.11	1,886.34	1,267.44
13	93.72	838.28	199.89	35.86	1,496.83	181.34	1,832.33	1,249.46
14	103.65	795.78	184.98	34.11	1,802.48	170.1	1,859.1	1,211.42
15	102.70	785.32	204.52	31.92	1,777.28	186.74	1,749.18	1,169.24
16	104.08	703.28	193.70	35.39	1,692.64	186.52	2,052	1,125.81
17	94.03	742.59	185.93	36.27	1,595.41	181.47	2,052	1,279.53
18	97.11	814.63	188.76	34.58	1,884	169.58	1,787.44	1,257.41
19	106.65	787.93	210.14	32.83	1,733.15	166.14	1,713.3	1,217.49
20	103.43	704.53	195.66	32.02	1,726.68	188.77	1,827.45	1,173.7
21	93.05	741.76	181.22	38.19	1,675.44	188.74	1,741.8	1,128.82
22	83.56	818.05	203.19	38.19	1,592.46	178.51	1,733.5	1,153.57
23	63.68	791.47	189.69	38.19	1,864	165.11	2,100	1,223.45
24	57.09	709.54	180.69	38.19	1,856.05	181.07	1,921.01	1,223.53
25	51.30	484.38	211.09	37.39	1,782.27	187.20	2,002.98	1,205.18
26	46.35	432.04	198.46	35.4	1,892.02	181.82	1,903.64	1,178.05
27	20.69	385.58	167.09	33.35	1,888.66	170.32	1,750.95	1,144.54
28	18.71	344.96	150.34	27.18	1,814.23	141.66	1,427.56	1,107.57
29	17.02	184.01	135.28	25.40	1,727.88	131.73	1,306.43	1,068.42
30	15.55	165.07	94.57	23.66	1,619.74	123.30	1,201.34	1,028.28.
31		149.07	85.20	22.26	1,309.18	114.92	1,079.68	987.72

Note: The unit of production is 10^6 m^3.

Continue

No.	9	10	11	12	13	14	15	16
	Anyang-Hebi	Feng	Lincheng	Lingshan	Yangquan	Heshun-Zuoquan	Lu'an	Jincheng
1								
2	868.61	538.69	212.09	114.97	1,789.50	2,096.20	1,337.99	1,739.16
3	1,322.19	1,329.04	261.42	124.07	2,389.78	2,360.28	1,971.91	2,225.86
4	1,314.48	1,336.68	262.61	123.18	2,370.41	2,257.80	1,981.14	2,254.94
5	1,156.34	1,227.95	254.73	137.65	2,260.76	2,095.54	2,062.37	2,041.27
6	1,269.02	1,249.89	241.88	127.94	2,229.80	2,297.88	2,115.88	2,259.10
7	1,295.55	1,325.17	220.80	117.10	2,008.55	2,194.25	1,968.27	2,198.19
8	1,211.17	1,231.76	221.48	136.82	2,210.73	2,039.11	2,075.24	1,975.29
9	1,290.16	1,121.26	243.89	128.75	2,201.31	2,277.41	2,095.56	2,214.54
10	1,297.24	1,177.17	235.06	119.19	2,002.68	2,188.07	1,969.10	2,152.53
11	1,216.22	1,314.17	245.83	139.12	2,011.89	2,044.90	2,058.37	1,996.09
12	1,110.94	1,242.19	227.55	131.66	2,212.08	2,153.93	2,075.60	2,165.21
13	1,217.45	1,218.85	225.24	122.59	2,076.81	2,288.11	1,975.44	2,087.73
14	1,244.47	1,233.75	228.54	125.31	2,131.04	2,168.87	2,026.74	1,963.17
15	1,178.23	1,149.15	224.51	121.88	2,209.64	2,011.90	2,075.80	1,942.20
16	1,199.88	1,335.12	227.71	119.29	2,032.76	2,254.08	1,976.38	2,072.48
17	1,184.49	1,188.21	224.01	127.79	2,136.74	2,204.90	1,991.78	1,987.65
18	1,130.64	1,143.92	228.24	139.41	2,213.89	2,060.16	2,340.29	2,307.25
19	1,309.73	1,221.42	221.89	133.15	2,038.69	2,242.20	2,277.01	2,107.83
20	1,257.94	1,375.25	233.77	121.43	2,090.75	2,187.86	2,091.79	1,971.27
21	1,134.61	1,154.68	222.09	138.69	2,206.17	2,047.88	2,142.76	2,322.20
22	1,150.27	1,224.41	240.33	132.28	2,043.45	2,242.82	2,014.49	2,120.58
23	1,194.23	1,377.66	228.05	123.41	2,118.92	2,314.97	2,012.60	1,985.01
24	1,126.10	1,289.95	236.34	131.00	2,217.34	2,184.10	2,095.74	2,309.50
25	1,155.21	1,180.13	222.98	123.96	2,047.67	2,025.70	1,989.38	2,121.74
26	1,197.10	1,278.21	204.66	115.22	2,130.83	2,199.43	2,003.23	1,982.30
27	1,130.44	1,191.57	147.23	94.93	2,227.87	2,170.01	2,079.47	1,779.13
28	1,032.01	1,036.85	130.52	71.65	2,057.18	2,031.59	1,981.94	1,254.83
29	853.66	952.39	108.42	64.57	1,231.73	1,556.49	1,604.93	1,125.21
30	790.11	872.76	83.74	52.89	1,033.19	1,440.14	1,507.56	999.27
31	734.37	582.33	61.89	36.89	873.56	1,335.12	1,405.63	687.35

Continue

No.	17	18	19	20	21	22	23	24
	Huodong	Taiyuan Xishan	Huozhou	Ningwu	Fugu	Liulin	Sanjiaobei	Xiangning
1								
2	1,669.05	701.70	815.60	560.31	386.12	552.64	523.09	465.84
3	2,148.69	1,164.42	1,165.10	887.45	1,176.01	1,377.82	1,279.79	1,090.12
4	2,268.26	1,195.2	1,168.87	1,123.80	1,221.24	1,406.20	1,305.23	1,055.27
5	2,141.28	1,107.22	1,054.27	1,174.28	1,134.37	1,305.39	1,187.65	1,055.26
6	1,931.37	996.44	1,134.63	1,129.97	1,123.71	1,187.05	1,200.26	1,218.21
7	2,269.60	1,112.33	1,110.42	984.11	1,196.89	1,234.39	1,361.09	1,145.23
8	2,235.51	1,165.15	1,015.59	1,047.93	1,121.24	1,353.38	1,255.57	1,090.83
9	2,112.51	1,095.32	1,119.56	1,058.70	1,024.64	1,283.88	1,244.62	1,109.92
10	1,934.03	1,000.09	1,093.20	1,046.03	1,078.77	1,191.21	1,288.34	1,064.07
11	2,262.34	1,104.21	1,007.35	997.94	1,160.57	1,440.00	1,200.03	1,064.00
12	2,232.25	1,152.01	1,055.26	997.28	1,100.28	1,219.84	1,399.87	1,099.50
13	2,122.06	1,090.45	1,029.83	1,007.55	1,022.64	1,204.84	1,237.03	1,061.41
14	1,961.28	1,005.10	986.22	997.87	1,187.07	1,225.99	1,293.98	1,272.00
15	1,979.47	1,200.00	1,116.81	1,053.71	1,111.92	1,293.81	1,309.95	1,106.68
16	2,145.19	1,118.53	1,066.58	1,038.57	1,107.06	1,402.77	1,372.00	1,067.70
17	2,121.26	1,096.16	1,134.88	999.16	1,026.45	1,371.28	1,301.22	1,141.93
18	1,970.11	1,008.64	989.48	1,047.42	1,095.54	1,306.20	1,205.45	1,125.70
19	2,312.00	1,192.92	1,081.21	1,078.58	1,169.36	1,206.95	1,260.23	1,068.88
20	2,199.10	1,290.29	1,060.20	1,073.07	1,125.07	1,385.97	1,284.17	1,081.83
21	2,102.91	1,097.15	1,080.30	1,010.29	1,036.01	1,239.96	1,210.14	1,119.00
22	1,931.03	1,003.35	1,070.69	996.14	1,083.00	1,200.71	1,336.87	1,070.24
23	2,312.00	1,179.30	988.35	1,100.03	1,164.24	1,271.50	1,265.01	1,095.77
24	2,194.58	1,200.00	1,009.74	1,161.47	1,118.06	1,274.22	1,339.03	1,124.31
25	2,106.79	1,097.74	1,007.69	1,118.79	1,035.22	1,382.70	1,316.55	1,080.78
26	1,942.84	1,007.50	718.55	1,049.00	953.63	1,289.09	1,223.86	1,006.95
27	1,764.91	917.48	248.51	933.41	571.84	1,225.10	935.63	621.48
28	1,127.66	836.89	219.39	702.64	523.46	1,129.48	831.67	594.84
29	1,008.19	524.38	193.08	622.09	482.70	1,032.71	753.43	573.22
30	909.88	477.26	170.51	553.73	448.92	591.19	509.68	311.14
31	829.02	437.37	151.70	503.00	219.33	535.86	466.45	302.04

Continue

No.	25	26	27	28	29	30	31	32
	Hancheng	Tongchuan	Ordos Basin Jura	Zhuozishan	Shizuishan	Hulusitai	Ruijigou	Leping
1								
2	949.51	254.56	535.32	28.00	47.09	18.81	13.62	20.56
3	1,791.45	406.73	1045.22	87.57	116.17	85.20	46.20	41.78
4	1,689.30	354.22	1028.80	90.57	116.84	118.06	52.61	39.70
5	1,517.46	360.90	1001.03	92.80	107.34	122.52	51.89	35.86
6	1,629.11	353.45	978.58	103.20	112.57	122.29	48.17	36.70
7	1,732.10	360.84	967.16	94.85	124.01	131.83	44.84	38.29
8	1,563.19	353.58	977.01	86.58	115.89	132.54	45.36	35.02
9	1,632.00	420.00	1,122.59	87.47	105.56	126.46	51.58	42.00
10	1,698.18	351.49	983.29	98.58	110.53	122.50	50.59	35.09
11	1,583.19	361.16	1,077.96	94.00	122.88	129.09	47.81	37.78
12	1,666.79	354.78	974.26	87.53	116.01	128.80	44.46	39.51
13	1,754.67	354.69	985.44	87.92	107.08	122.89	45.37	36.21
14	1,661.57	365.90	988.37	95.93	125.12	119.62	51.90	36.11
15	1,564.88	350.81	1,106.50	92.43	111.45	127.06	51.23	41.91
16	1,634.07	353.02	1,041.93	102.67	107.77	127.54	48.79	42.00
17	1,701.73	351.16	1,003.37	92.91	107.83	122.36	45.72	35.30
18	1,633.90	405.59	996.59	90.87	111.73	127.11	50.76	38.53
19	1,572.45	365.44	1,153.42	95.55	105.47	110.70	46.44	38.67
20	1,583.82	352.10	1,006.68	100.54	124.45	126.91	48.70	35.53
21	1,884.00	350.44	979.67	95.14	117.57	126.08	47.02	40.00
22	1,778.28	372.15	972.00	88.05	123.48	126.04	45.70	35.58
23	1,689.87	353.62	1,145.39	87.63	123.92	128.27	47.43	39.72
24	1,570.34	376.84	1,005.48	89.66	115.69	132.54	49.40	35.35
25	1,460.02	257.24	1,004.29	99.35	106.08	127.76	50.21	40.82
26	1,154.55	224.65	668.62	94.67	96.97	120.21	49.44	38.33
27	1,068.29	168.16	556.58	88.22	63.21	101.26	46.88	35.32
28	1,013.33	147.36	400.99	73.12	57.74	94.44	43.66	32.26
29	814.96	72.20	349.26	67.68	53.13	88.19	40.78	20.90
30	782.62	63.45	116.89	63.57	40.90	82.40	32.27	19.19
31	758.09	12.98	105.39	40.14	38.03	65.97	30.10	10.26

Continue

No.	33	34	35	36	37	38	39	40
	Fengcheng	Lianshao	Tianfu	Libixia	Songzao	Northwest Guizhou	Guishan	Enhong
1								
2	90.05	59.68	170.03	105.42	165.12	225.16	43.73	112.84
3	180.62	135.97	253.41	181.52	278.39	603.51	117.55	255.83
4	167.91	138.71	247.86	165.65	253.59	622.61	125.92	257.68
5	151.20	131.04	232.29	177.30	258.48	622.71	119.34	239.21
6	159.23	118.55	239.63	179.01	260.60	655.23	111.34	218.10
7	168.80	126.77	231.71	195.58	294.59	656.49	113.52	235.58
8	158.58	140.77	212.30	179.25	247.40	678.73	124.32	262.48
9	171.46	133.33	249.05	184.07	257.04	636.90	115.37	246.12
10	186.79	123.76	235.45	179.15	249.44	758.42	125.83	224.90
11	178.94	133.57	232.33	168.64	250.43	654.01	113.47	241.57
12	172.36	150.49	227.66	179.43	270.10	654.38	115.60	270.70
13	167.08	143.68	231.96	163.81	246.13	681.29	107.48	254.73
14	162.48	134.24	213.90	195.58	294.59	680.39	118.07	233.46
15	159.39	141.68	231.88	184.12	242.56	719.23	125.83	284.68
16	156.63	155.68	225.94	179.17	282.67	731.04	115.52	271.17
17	175.18	126.60	247.51	165.08	250.39	692.73	125.83	262.72
18	193.73	158.83	217.44	179.45	294.59	789.27	125.83	241.94
19	187.61	152.77	231.80	164.44	252.19	726.40	115.50	270.32
20	180.21	142.66	212.04	198.82	270.54	715.27	106.45	296.42
21	199.02	156.72	231.71	182.08	269.86	758.37	119.56	271.56
22	169.97	164.13	220.92	179.01	247.61	744.29	125.83	248.93
23	185.28	157.11	231.99	163.39	274.48	803.97	115.06	279.30
24	199.14	146.38	224.36	179.03	248.21	794.64	105.15	306.27
25	186.28	162.10	231.73	155.15	285.34	756.27	116.33	280.88
26	151.26	169.86	222.11	179.37	265.68	694.76	108.96	257.63
27	142.84	163.01	232.37	172.63	270.02	402.14	106.77	234.56
28	136.08	152.17	146.26	179.42	175.32	371.49	97.58	214.58
29	111.16	139.99	118.81	118.14	152.23	344.81	88.32	140.84
30	108.99	114.26	58.72	101.03	56.97	164.60	48.40	127.96
31	107.52	105.88	48.21	41.79	49.69	151.10	42.60	116.31

Continue

No.	41	42	43	44	45	46	47	48
	Xuanwei	Liupanshui	Xingyi	Zhina	Guiyang	Hongmao	Luocheng	Heshan
1								
2	77.05	75.04	77.99	86.64	51.77	45.28	35.12	69.23
3	222.97	209.74	210.46	211.07	138.20	119.05	94.60	218.64
4	258.29	238.69	233.46	234.31	154.53	136.49	113.70	235.00
5	246.11	226.69	221.90	220.86	147.88	131.89	111.63	211.47
6	232.01	218.77	211.52	203.82	137.55	123.60	105.57	211.42
7	236.74	216.16	215.55	210.29	138.77	114.60	98.33	238.75
8	258.11	226.35	236.08	230.81	148.97	122.19	99.30	224.93
9	246.51	212.09	217.72	223.25	143.79	138.84	106.22	200.36
10	278.09	213.11	246.78	206.35	133.49	136.65	104.12	230.44
11	284.56	236.02	254.40	214.08	136.92	127.72	97.58	217.45
12	252.59	255.60	247.48	236.58	150.10	131.58	98.74	223.49
13	236.75	239.87	252.71	228.99	145.10	144.20	105.79	200.45
14	244.60	249.65	233.47	212.14	159.60	141.23	113.40	212.47
15	271.84	231.15	215.42	246.98	141.66	132.14	98.04	230.84
16	260.94	215.11	223.81	224.81	146.14	152.09	105.71	224.47
17	232.89	219.75	224.91	231.23	137.49	139.80	101.48	200.46
18	272.55	225.24	233.36	229.31	145.99	146.78	95.13	225.65
19	267.46	217.48	219.33	233.36	160.80	139.37	100.91	228.48
20	203.17	223.20	243.73	250.33	147.07	143.55	115.61	230.31
21	269.25	225.98	221.37	253.92	137.32	156.35	103.83	206.26
22	274.09	246.92	220.18	247.72	146.70	153.23	98.17	200.21
23	252.21	223.05	221.51	229.31	163.20	143.12	91.49	167.38
24	231.95	223.04	238.02	240.44	149.00	161.09	84.83	165.93
25	285.49	230.19	222.57	243.52	139.20	158.46	66.49	149.89
26	283.01	259.93	159.70	237.72	154.06	148.67	61.50	133.85
27	212.57	249.10	143.62	220.33	149.10	122.74	27.72	48.49
28	194.38	192.46	105.94	202.88	150.28	113.27	25.55	43.01
29	175.16	175.49	92.42	132.41	141.02	104.88	23.59	38.11
30	94.03	155.32	37.68	121.10	130.37	96.84	21.82	33.93
31	82.99	104.54	32.67	111.17	96.72	55.56	20.24	6.04

Continue

No.	49	50	51	52	53	54	55	56
	Baiyanghe	Aiweiergou	Huhehu Depression	Huolinhe	Hegang	Jixi	Shuangya-shan	Boli
1								
2	93.62	40.10	32.97	17.97	57.85	53.42	50.68	74.60
3	342.49	93.93	80.67	48.78	141.53	131.79	125.03	132.96
4	409.71	99.27	86.40	53.15	144.34	132.54	125.75	114.21
5	389.14	91.45	80.05	48.85	131.34	121.76	115.52	126.59
6	355.90	83.79	73.06	44.38	133.92	124.55	118.56	133.96
7	348.63	87.36	76.75	46.22	145.67	132.91	127.08	114.98
8	386.55	95.51	85.45	52.73	133.26	123.65	118.30	127.20
9	375.83	91.01	81.77	50.64	134.92	112.57	107.71	136.32
10	343.99	83.34	74.82	48.24	143.86	118.43	113.89	135.52
11	346.18	84.28	77.49	47.78	134.81	132.53	128.20	116.67
12	407.73	88.49	85.02	55.46	122.88	125.29	121.27	137.10
13	406.52	99.30	93.87	48.02	146.48	115.73	112.00	133.68
14	408.00	90.47	82.10	48.92	148.65	135.80	130.37	114.98
15	352.78	90.50	81.62	50.18	126.46	137.91	113.95	138.03
16	365.29	83.05	83.13	55.44	132.82	115.60	110.16	136.83
17	364.54	88.55	88.19	58.40	146.67	122.66	117.22	126.46
18	402.15	98.68	83.64	55.34	137.53	137.09	131.49	138.43
19	391.62	82.79	80.82	52.80	127.77	127.18	121.70	118.81
20	347.12	86.57	96.24	52.37	146.20	120.67	132.15	119.59
21	395.44	94.46	93.45	52.69	138.30	137.37	123.32	139.94
22	389.27	96.53	96.47	57.60	131.25	128.59	111.91	120.57
23	380.48	89.79	94.47	52.69	147.85	118.11	111.58	120.71
24	352.85	99.20	100.05	51.55	139.81	114.65	133.48	141.28
25	343.32	88.07	97.20	53.58	127.39	136.58	127.30	132.01
26	350.51	85.36	93.83	53.72	85.20	130.13	117.35	141.98
27	346.21	78.24	86.09	51.90	77.34	120.20	81.89	121.87
28	350.61	71.59	70.04	40.43	70.06	84.28	73.42	79.53
29	324.42	52.53	63.90	36.61	48.49	75.85	67.25	68.21
30	254.57	47.90	58.31	33.14	44.82	69.65	46.86	58.98
31	230.72	43.84	37.55	24.58	41.80	49.56	43.18	25.41

Continue

No.	57	58	59	60	61			
	Hongyang	Fuxin	Tiefa	Huainan	Huaibei			
1								
2	197.24	48.00	57.39	351.97	432.17			
3	243.61	61.43	73.45	1,100.89	1,165.17			
4	324.35	62.24	74.41	1,138.64	1,144.33			
5	320.79	64.34	67.36	1,058.40	1,056.31			
6	298.19	61.07	76.08	958.61	1,088.35			
7	321.45	68.30	74.50	951.51	1,067.66			
8	311.63	64.33	67.17	1,105.31	1,096.95			
9	310.41	67.15	75.26	1,050.60	1,035.67			
10	284.60	63.22	73.14	970.69	996.02			
11	304.49	69.57	75.48	981.06	1,154.88			
12	295.29	66.94	70.10	1,092.19	1,140.34			
13	295.94	61.35	79.19	1,048.09	1,070.48			
14	277.77	71.97	78.05	985.31	1,006.54			
15	304.48	71.60	73.21	994.32	1,036.21			
16	294.10	67.87	82.56	1,083.12	1,049.55			
17	283.97	69.60	74.45	1,050.26	1,006.74			
18	297.38	65.48	75.20	1,003.00	1,173.08			
19	322.89	66.50	77.32	959.06	1,021.65			
20	305.97	77.98	72.78	1,088.69	1,079.41			
21	283.37	73.90	76.63	1,148.24	1,089.13			
22	305.41	69.13	74.60	963.49	1,005.52			
23	302.88	78.37	84.41	992.37	1,023.24			
24	313.83	77.85	76.28	1,112.69	1,109.07			
25	294.09	70.34	82.37	1,054.38	1,058.28			
26	240.18	63.17	76.05	988.16	1,088.77			
27	220.29	52.95	69.79	783.96	834.00			
28	202.49	47.91	57.48	724.42	712.82			
29	186.12	42.67	51.67	680.20	616.61			
30	141.41	33.17	47.04	644.34	366.36			
31	127.74	30.23	36.76	504.13	317.90			

Annexed Table 7 Annual production of a part of the Chinese CBM prospects with vertical well and multi-branch horizontal well

	Hancheng	Ningwu	Jincheng	Anyang-Hebi	Jiyu	Dacheng
1						
2	1,078.50	560.31	1,591.68	803.31	1,175.91	1,137.11
3	1,764.65	887.45	2,005.50	1,274.24	1,497.66	1,571.71
4	1,696.78	1,123.80	2,158.59	1,270.49	1,724.12	1,896.80
5	1,528.94	1,174.28	2,044.07	1,116.43	1,742.47	1,870.71
6	1,704.10	1,129.97	2,245.20	1,109.48	1,601.98	1,669.64
7	1,755.79	984.11	2,202.22	1,176.71	1,600.70	1,668.88
8	1,537.37	1,047.93	1,963.35	1,127.59	1,509.82	1,777.80
9	1,776.76	1,058.70	2,106.14	1,166.75	1,538.89	1,776.89
10	1,691.95	1,046.03	1,968.39	1,128.36	1,547.46	1,677.40
11	1,569.42	997.94	1,998.84	1,121.39	1,565.56	1,707.65
12	1,715.57	997.28	1,965.42	1,139.95	1,524.30	1,693.64
13	1,783.51	1,007.55	2,058.25	1,194.64	1,648.33	1,721.64
14	1,592.02	997.87	2,005.88	1,167.70	1,571.93	1,685.36
15	1,708.12	1,053.71	2,036.93	1,192.44	1,617.91	1,720.56
16	1,765.75	1,038.57	1,981.11	1,158.71	1,563.59	1,788.92
17	1,591.24	999.16	2,104.66	1,171.75	1,663.41	1,716.92
18	1,761.66	1,047.42	1,977.11	1,160.70	1,563.09	1,741.21
19	1,854.80	1,078.58	2,041.11	1,267.64	1,563.02	1,827.47
20	1,708.01	1,073.07	1,994.07	1,161.28	1,598.12	1,842.26
21	1,599.41	1,010.29	1,975.25	1,171.69	1,564.23	1,891.92
22	1,613.81	996.14	1,987.84	1,216.72	1,710.55	1,759.34
23	1,855.76	1,100.03	1,986.02	1,172.05	1,617.51	1,787.28
24	1,754.18	1,161.47	1,978.32	1,155.19	1,655.83	1,822.21
25	1,630.53	1,118.79	1,991.01	1,137.46	1,584.85	1,777.28
26	1,285.68	1,049.00	1,998.47	1,146.65	1,596.08	1,791.05
27	1,172.90	933.41	1,877.53	987.84	1,379.86	1,619.81
28	1,059.21	702.64	1,535.38	896.17	1,307.38	1,360.45
29	834.10	622.09	1,294.73	756.41	1,193.39	1,236.29
30	689.59	553.73	1,082.46	660.39	990.18	1,109.30
31	667.90	503.00	917.71	535.33	890.75	909.57

Note: Two well types plan means that theratio of the cotrolling area of vertical well and that of multi-lateral well is 4:1; the unit of production is 10^6 m^3.

Annexed Table 8 Annual investment of the Chinese CBM prospects with vertical well

No.	1	2	3	4	5	6	7	8
	Daqingshan	Xuanxia	Xinglong	Kailuan	Jiyu	Liujiang	Dacheng	Jiaozuo
1	34,837.03	227,915.19	55,106.33	16,155.14	339,598.23	84,568.90	390,501.90	502,434.30
2								
3								
4								
5	7,717.67	76,805.06	13,470.38					
6						18,162.25		
7							105,602.28	
8			13,470.38		80,814.37			
9	8,575.19	70,221.77						
10				3,015.49		18,162.25		
11			8,980.25				98,416.01	71,226.81
12		116,304.81						
13	16,078.48				92,409.63			
14			22,450.63			15,931.80		
15							23,426.57	
16		96,554.94		2,584.71				65,825.24
17	10,718.99		13,470.38		177,498.10			
18						46,202.23		
19							73,570.71	
20		94,360.51	13,470.38	7,323.34				
21								247,687.34
22					85,517.16		204,463.80	
23			16,164.46			25,490.89		
24								
25					81,990.71			
26								
27								
28								
29								
30								
31								

Note: The unit of investment is 10^6 USD.

Continue

No.	9	10	11	12	13	14	15	16
	Anyang-Hebi	Fengfeng	Lincheng	Lingshan	Yangquan	Heshun-Zuoquan	Lu’an	Jincheng
1	557,266.20	635,805.57	103,983.54	49,475.57	501,738.48	755,026.58	578,455.06	326,490.00
2								
3								
4	113,337.77		19,809.82	8,684.52	167,819.75		193,882.03	105,330.94
5		135,337.72				108,379.75		
6								
7	96,348.62		12,381.14	9,925.16	165,868.35		146,466.84	86,618.03
8			12,381.14			115,605.06		
9		146,071.77						
10			12,381.14	9,925.16	255,834.56		118,465.82	
11	96,348.62					438,287.34		463,295.44
12		65,599.72	34,667.19					
13				4,962.58	206,847.59		103,388.35	
14	56,707.27		2,476.23	12,406.46				9,696.08
15		243,905.32	22,286.05			180,632.91		
16	226,598.86			4,962.58	204,896.20		400,557.09	184,055.57
17			7,428.68	9,925.16				
18		155,075.95	12,381.14			166,182.28		
19			12,381.14		220,507.34		161,544.30	
20	113,261.01			12,406.46				56,479.47
21		154,671.65	19,809.19			357,305.95		
22					214,826.46		168,006.08	
23	113,261.01		22,286.05	9,925.16				23,062.30
24		118,978.23						
25					214,653.16	202,308.86	188,431.90	
26								
27								
28								
29								
30								
31								

Continue

No.	17	18	19	20	21	22	23	24
	Huodong	Taiyuan Xishan	Huozhou	Ningwu	Fugu	Liulin	Sanjiaobei	Xiangning
1	300,887.09	236,340.38	195,557.59	296,379.75	205,479.62	502,733.92	446,143.42	260,561.90
2								
3								
4								72,982.90
5			41,940.78		35,456.49		111,949.66	
6	91,161.63	63,823.44				91,898.20		
7				76,576.00				22,981.84
8			35,949.24				62,442.03	
9					30,621.52			
10	79,619.14	56,734.22				212,375.32		109,712.86
11			29,974.94	66,683.91			183,100.63	
12								
13			89,890.33		85,762.52	63,671.51	52,582.76	
14	151,570.13	119,098.94						
15				55,777.48		110,788.43	98,592.68	
16			35,949.24					79,184.06
17					57,213.86			
18	107,442.15	80,817.13	35,949.24				98,944.80	
19						159,178.73		47,914.34
20			39,544.16	139,829.24				
21					49,155.57		141,316.20	
22	105,523.54	77,981.44				91,686.97		40,069.05
23			39,544.16					
24						101,093.94	75,869.39	
25								
26								
27								
28								
29								
30								
31								

Continue

No.	25	26	27	28	29	30	31	32
	Hancheng	Tongchuan	Ordos Basin Jura	Zhuozishan	Shizuishan	Hulusitai	Rujigou	Leping
1	887,758.23	201,729.62	210,382.41	50,231.52	63,249.62	70,391.14	31,355.82	25,252.15
2								
3			37,362.04					
4		27,887.35		8,922.23				
5	181,051.01		37,362.04		13,370.85	10,989.91		4,050.91
6		27,887.35						
7			37,362.04				4,673.77	
8	133,385.32	80,024.58	32,024.59	8,922.23				12,377.78
9			58,761.67		12,155.32	9,768.81		
10		29,099.85						4,050.91
11	130,616.33		40,564.49					
12		41,224.78		6,691.67			4,673.77	
13			64,099.10		21,879.57	9,768.81		7,426.67
14		33,949.82						
15	94,382.37		48,036.90	15,613.90				6,526.47
16		72,749.62			7,293.19			
17			74,773.97			26,864.23	9,347.54	6,301.42
18		24,249.87		11,152.78	15,072.59			
19	41,534.59		32,024.59					
20		48,499.75						6,751.52
21	327,732.78		76,908.95		13,370.85	14,653.22	2,336.89	
22		36,374.81		6,691.67				5,851.32
23		9,699.82	32,024.59	6,691.67			4,673.77	
24								7,201.62
25								
26								
27								
28								
29								
30								
31								

Continue

No.	33	34	35	36	37	38	39	40
	Fengcheng	Lianshao	Tianfu	Libixia	Songzao	Northwest Guizhou	Guishan	Enhong
1	556,687.72	289,156.96	91,998.73	86,443.04	136,708.86	475,601.27	82,342.51	292,306.84
2								
3			21,682.89					
4				22,861.30	28,282.03	76,710.52		
5	122,020.04		24,511.09					63,025.41
6		73,464.33		53,971.53	82,489.24	56,068.87	15,610.32	
7			51,850.38					
8	115,345.41			16,262.16	23,568.35			59,577.84
9			28,045.71			258,001.39	34,482.51	
10		81,586.81		28,753.39	45,722.61			
11			31,581.59					
12				49,493.54	77,775.57	117,864.27		
13			39,359.15				22,600.01	
14		72,110.58		16,497.85				
15			32,995.70		51,850.38			
16	114,300.75	123,552.94		31,110.23			28,424.76	59,038.25
17			30,638.86		65,991.39	229,507.59		
18				45,958.29				
19			35,823.90		30,874.54			
20	242,579.37	106,135.25		17,911.95		147,385.19	26,327.86	125,296.34
21			35,588.22		51,850.38			
22	130,155.32			31,817.28		132,604.94		67,227.42
23			33,467.06		61,277.72			
24		112,903.99		36,766.63			24,463.94	
25			35,116.85		34,645.48			
26				24,982.46				
27								
28								
29								
30								
31								

Continue

No.	41	42	43	44	45	46	47	48
	Xuanwei	Liupanshui	Xingyi	Zhina	Guiyang	Hongmao	Luocheng	Heshan
1	621,394.30	489,344.05	583,968.99	513,942.03	361,576.71	149,791.01	73,000.97	145,565.70
2								
3								
4								
5								30,627.89
6	126,836.58	80,015.38	130,777.34	96,225.20	58,308.49			
7						32,802.18	10,472.66	
8			92,386.70					70,735.84
9	300,193.92	105,422.99						
10			258,970.13	98,994.37	64,396.14			
11		199,320.63				28,907.84	10,234.66	
12								
13	133,631.39				138,462.66		24,753.58	45,698.76
14				207,128.10				
15			168,689.49			63,838.62		
16	168,007.85	122,471.77						
17			86,642.44	54,608.16	85,702.97			63,929.65
18							15,947.01	
19	223,692.66	119,783.76	182,475.70	119,563.61		29,711.16		
20								
21		121,993.15			91,790.61			21,877.06
22			103,875.20			46,212.38		4,861.57
23	204,798.23			119,563.61				
24		118,384.18						
25					116,141.24			
26								
27								
28								
29								
30								
31								

Continue

No.	49	50	51	52	53	54	55	56
	Baiyanghe	Aiweiergou	Huhehu Depression	Huolinhe	Hegang	Jixi	Shuangyashan	Boli
1	145,945.57	60,040.19	278,701.52	455,592.78	163,137.85	161,783.42	143,806.46	165,767.72
2								
3								
4								47,473.90
5					38,487.19	36,320.30	33,237.05	
6	31,515.39	9,813.43	60,725.84	108,884.24				
7								49,203.75
8					31,614.48			65,028.38
9				38,427.91		38,785.97	36,006.78	
10	40,771.66	7,009.59	57,470.03					
11				193,425.70				64,880.99
12		20,327.82	106,388.48		75,855.82			
13	51,791.03					69,696.89	61,063.53	
14				96,069.76				68,193.29
15			48,837.39		39,174.43			
16	30,854.23	10,981.70		96,069.76		39,411.42	36,006.78	56,324.82
17								
18			90,028.29		44,800.59		30,467.27	
19	35,261.97	9,346.13		76,855.81		42,502.49		71,358.20
20								
21		5,841.33	57,470.03	134,497.72	41,923.54			
22							49,984.54	72,149.46
23	26,446.48	12,850.92	81,888.72			50,377.57		
24				116,569.94				53,803.76
25	41,873.59							
26								
27								
28								
29								
30								
31								

Continue

No.	57	58	59	60	61			
	Hongyang	Fuxin	Tiefa	Huainan	Huanbei			
1	107,182.28	69,218.61	85,082.43	207,290.51	348,109.24			
2								
3								
4		8,392.66			70,768.53			
5			17,102.00					
6	21,839.49	12,588.99		55,483.28	70,736.01			
7								
8		8,392.66	17,102.00		40,083.73			
9								
10	21,839.49	12,588.99	8,551.00	43,714.06	188,694.43			
11								
12			17,102.00					
13		16,785.32			70,768.53			
14	21,839.49			34,360.72	47,157.34			
15			17,102.00					
16	43,678.99	8,392.66	17,102.00		117,925.87			
17		16,785.32						
18			8,551.00					
19		16,785.32		86,616.43	143,894.94			
20			17,102.00					
21	32,759.24							
22		20,981.65	17,102.00	43,559.66	117,893.35			
23								
24			12,826.51		70,736.01			
25								
26								
27								
28								
29								
30								
31								

Annexed Table 9 Annual investment of of a part of the Chinese CBM prospects with vertical well and multi-branch horizontal well

	Hancheng	Ningwu	Jincheng	Anyang-Hebi	Jiyu	Dacheng
1	839,412.28	162,496.71	329,669.24	316,171.14	356,723.04	839,412.28
2						
3						
4						
5	205,141.14		84,041.76			205,141.14
6				58,230.41	56,366.08	
7		56,515.97			56,279.71	
8	213,037.09		68,761.44	32,507.51		213,037.09
9				56,872.99		
10			30,560.65		56,322.89	
11	163,864.05	45,197.38	61,121.28		65,656.05	163,864.05
12			30,560.65	48,791.53		
13						
14	139,623.16	39,492.28	114,602.41	60,632.59	46,924.95	139,623.16
15					46,903.35	
16			38,220.91	48,771.34		
17	155,691.65	41,430.94			140,753.29	155,691.65
18			80,221.68	105,664.54		
19						
20			30,560.65		56,322.89	
21	312,212.66	79,114.65	53,481.13	56,913.35		312,212.66
22			22,920.48		56,301.30	
23			22,940.59	52,832.27	46,903.35	
24			61,121.28			
25						
26						
27						
28						
29						
30						
31						

Note: Two well types plan means that theratio of the cotrolling area of vertical well and that of multi-lateral well is 4:1; the unit of investment is 10^6 USD.

Annex 2 Outcomes of Economic Evaluation of Other Chinese CBM Prospects

1. Daqingshan

Through the economic evaluation of Daqingshan prospect, we got the result that the NPV is 32,209.43×10^3 USD when the basic discount rate is 8%, and the NPV will be 23,113.46×10^3 USD when the basic discount rate is 10%, while, the NPV will be 16,020.53×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 10. The analysis shows that the CBM price is the most sensitive factor and can cause the most influence on the NPV; the following data are the CBM production and the operating cost. In term of economic evaluation of the CBM development, the outcome of this sensitivity analysis is general for all CBM prospects.

Annexed Table 10 Sensitivity analysis of Daqingshan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-1,003.66	7,508.44	16,020.53	24,532.63	33,044.72
NPV (Production)	4,261.2	10,140.86	16,020.53	21,900.2	27,779.87
NPV(Operation cost)	21,285.38	18,652.96	16,020.53	13,388.11	10,755.68

2. Kailuan

Through the economic evaluation of Kailuan prospect, we got the result that the NPV is 11,631.30×10^3 USD when the basic discount rate is 8%, and the NPV will be 7,593.63×10^3 USD when the basic discount rate is 10%, while, the NPV will be 4,508.44×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 11.

Annexed Table 11 Sensitivity analysis of Kailuan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-1,646.84	1,467.15	4,508.44	7,549.73	10,591.01
NPV(Production)	296.92	2,407.69	4,508.44	6,609.19	8,709.94
NPV(Operation cost)	6,389.52	5,448.98	4,508.44	3,567.9	2,627.36

3. Fengfeng

Through the economic evaluation of Fengfeng prospect, we got the result that the NPV is 174,163.38×10^3 USD when the basic discount rate is 8%, and the NPV will be 57,961.158×10^3 USD when the basic discount rate is 10%, while, the NPV will be -30,221.63×10^3 USD when the basic discount rate is 12%. It can be seen that it is a marginal prospect, and when the favorable change in price and operation cost, its development would realize a certain economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 12.

Annexed Table 12 Sensitivity analysis of Fengfeng (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-256,629	-141,272	-30,221.6	79,641.61	189,504.8
NPV(Production)	-184,373	-106,109	-30,221.6	45,665.65	121,552.9
NPV(Operation cost)	37,729.39	3,754.342	-30,221.6	-64,197.6	-98,173.6

4. Lincheng

Through the economic evaluation of Licheng prospect, we got the result that the NPV is 38,281.86×10^3 USD when the basic discount rate is 8%, and the NPV will be 18,377.81×10^3 USD when the basic discount rate is 10%, while, the NPV will be 3,159.47×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 13.

Annexed Table 13 Sensitivity analysis of Licheng prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-37,817.1	-17,290.4	3,159.468	23,609.34	44,059.2
NPV(Production)	-25,091.7	-10,966.1	3,159.468	17,285.08	31,410.68
NPV(Operation cost)	15,808	9,483.734	3,159.468	-3,164.8	-9,489.05

5. Lingshan

Through the economic evaluation of Lingshan prospect, we got the result that the NPV is 32,918.43×10^3 USD when the basic discount rate is 8%, and the NPV will be 20,762.06×10^3 USD when the basic discount rate is 10%, while, the NPV will be 11,499.58×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 14.

Annexed Table 14 Sensitivity analysis of Lingshan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-10,301.01	599.28	11,499.58	22,399.89	33,300.18
NPV(Production)	-3,559.03	3,970.29	11,499.58	19,028.89	26,558.21
NPV(Operation cost)	18,241.57	14,870.57	11,499.58	8,128.58	4,757.6

6. Fugu

Through the economic evaluation of Fugu prospect, we got the result that the NPV is 26,799.10×10^3 USD when the basic discount rate is 8%, and the NPV will be -4,847.77×10^3 USD when the basic discount rate is 10%, while, the NPV will be -29,115.62×10^3 USD when the basic discount rate is 12%. It can be seen that it is a marginal prospect. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 15.

Annexed Table 15 Sensitivity analysis of Fugu prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV (Price)	-96,309.71	-61,770.08	-29,115.62	2,849.99	34,770.2
NPV (Production)	-72,836.47	-50,477.28	-29,115.62	-7,918.76	13,232.3
NPV (Operation cost)	-7,532.30	-18,301.27	-29,115.62	-40,307.62	-50,904.9

7. Liulin

Through the economic evaluation of Liulin prospect, we got the result that the NPV is 9,907.86×10^3 USD when the basic discount rate is 8%, and the NPV will be -59,194.9×10^3 USD when the basic discount rate is 10%, while, the NPV will be -111,619.97×10^3 USD when the basic discount rate is 12%. It is can seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 16. When there is a great favorable change in price, its development can realize a certain economic benefit.

Annexed Table 16 Sensitivity analysis of Liulin prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-271,637.8	-189,393.2	-111,619.97	-34,831.68	41,024.56
NPV(Production)	-216,731.6	-163,552	-111,619.97	-60,423.38	-10,158.85
NPV(Operation cost)	-59,504.49	-85,096.23	-111,619.97	-136,831.11	-164,590.17

8. Sanjiaobei

Through the economic evaluation of Sanjiaobei prospect, we got the result that the NPV is 21,959.03×10^3 USD when the basic discount rate is 8%, and the NPV will be -44,479.01×10^3 USD when the basic discount rate is 10%, while, the NPV will be -94,768.86×10^3 USD when the basic discount rate is 12%. It is can seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 17.

Annexed Table 17 Sensitivity analysis of Sanjiaobei prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-249,758.3	-170,374.7	-94,768.86	-20,951.23	52,823.531
NPV(Production)	-195,554.1	-144,799.2	-94,768.86	-45,840.71	3,044.57
NPV(Operation cost)	-44,947	-69,836.48	-94,768.86	-120,599.06	-145,782.37

9. Xiangning

Through the economic evaluation of Xiangning prospect, we got the result that the NPV is -14,112.99×10^3 USD when the basic discount rate is 8%, and the NPV will be -52,276.94×10^3 USD when the basic discount rate is 10%, while, the NPV will be -81,129.44×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 18. When there is a great favorable change in price, its development can realize a certain economic benefit.

Annexed Table 18 Sensitivity analysis of Xiangning (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-166,495.2	-123,292.3	-81,129.44	-41754.11	-3187.57
NPV(Production)	-136,458.1	-108,72	-81,129.44	-54946.68	-29210.05
NPV(Operation cost)	-54,462.08	-67,881.81	-81,129.44	-94759.97	-109281.42

10. Tongchuan

Through the economic evaluation of Tongchuan prospect, we got the result that the NPV is -43,661.57×10^3 USD when the basic discount rate is 8%, and the NPV will be -64,286.00×10^3 USD when the basic discount rate is 10%, while, the NPV will be -79,947.27×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 19.

Annexed Table 19 Sensitivity analysis of Tongchuan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-148,546.3	-112,919.3	-79,947.27	-48,966.73	-17,992.73
NPV(Production)	-123,091.9	-101,449.4	-79,947.27	-59,416.46	-38,892.21
NPV(Operation cost)	-59,041.25	-69,493.41	-79,947.27	-90,670.05	-101,880.09

11. Ordos Basin Jura

Through the economic evaluation of Ordos Basin Jura prospect, we got the result that the NPV is -6,564.59×10^3 USD when the basic discount rate is 8%, and the NPV will be -36,223.05×10^3 USD when the basic discount rate is 10%, while, the NPV will be -58,585.56×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 20. When there is a great favorable change in price and market, its development can realize a certain economic benefit.

Annexed Table 20 Sensitivity analysis of Ordos Basin Jura prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-143,808.2	-100,042.8	-58,585.56	-17,132.37	24,318.05
NPV(Production)	-113,681.9	-86,056.32	-58,585.56	-31,116.54	-3,650.30
NPV(Operation cost)	-30,614.43	-44,599.08	-58,585.56	-72,572.04	-86,558.52

12. Zhuozishan

Through the economic evaluation of Zhuozishan prospect, we got the result that the NPV is 8,112.86×10^3 USD when the basic discount rate is 8%, and the NPV will be 630.46×10^3 USD when the basic discount rate is 10%, while, the NPV will be -7,259.73×10^3 USD when the basic discount rate is 12%. It can be seen that it is a marginal prospect. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 21. When there is a great favorable change in price and production, its development can realize a certain economic benefit.

Annexed Table 21 Sensitivity analysis of Zhuozishan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-23,900.18	-15,385.84	-7,259.73	711.42	8682.57
NPV(Production)	-18,060.75	-12,664.28	-7,259.73	-1977.82	3304.09
NPV(Operation cost)	-1,881.266	-4,570.49	-7,259.73	-10036.04	-12767.41

13. Shizuishan

Through the economic evaluation of Shizuishan prospect, we got the result that the NPV is 5,632.23×10^3 USD when the basic discount rate is 8%, and the NPV will be -4,158.37×10^3 USD when the basic discount rate is 10%, while, the NPV will be -11,615.80×10^3 USD when the basic discount rate is 12%. It can be seen that it is a marginal prospect. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 22. When there is a favorable change in price and production, its development can realize a certain economic benefit.

Annexed Table 22 Sensitivity analysis of Shizuishan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-31,947.76	-21,696.92	-11,615.80	-1,869.19	7,877.41
NPV(Production)	-24,778.62	-18,181.24	-11,615.80	-5,157.41	1,300.96
NPV(Operation cost)	-4,959.60	-8,327.57	-11,615.80	-14,957.23	-18,307.90

14. Hulusitai

Through the economic evaluation of Hulusitai prospect, we got the result that the NPV is 11,197.71×10^3 USD when the basic discount rate is 8%, and the NPV will be 1,140.87×10^3 USD when the basic discount rate is 10%, while, the NPV will be -10,519.51×10^3 USD when the basic discount rate is 12%. It can be seen that it is a marginal prospect. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 23. When there is a favorable change in price and production, its development can realize a certain economic benefit.

Annexed Table 23 Sensitivity analysis of Hulusitai prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-32,224.44	-21,001.65	-10,519.51	87.03	10296.67
NPV(Production)	-24,556.28	-17,387.27	-10,519.51	-3610.70	3129.97
NPV(Operation cost)	-3,477.92	-6,715.81	-10,519.51	-13914.95	-17530.51

15. Rujigou

Through the economic evaluation of Rujigou prospect, we got the result that the NPV is 3,259.91×10^3 USD when the basic discount rate is 8%, and the NPV will be -1,696.58×10^3 USD when the basic discount rate is 10%, while, the NPV will be -5,474.10×10^3 USD when the basic discount rate is 12%. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 24.

Annexed Table 24 Sensitivity analysis of Rujigou prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-14,100.86	-9,667.13	-5,474.10	-1204.61	2981.15
NPV(Production)	-11,129.68	-8,304.87	-5,474.10	-2616.76	156.84
NPV(Operation cost)	-2,566.063	-4,011.82	-5,474.10	-6845.96	-8250.62

16. Leping

Through the economic evaluation of Leping prospect, we got the result that the NPV is -9,723.06×10^3 USD when the basic discount rate is 8%, and the NPV will be -11,616.25×10^3 USD when the basic discount rate is 10%, while, the NPV will be-13,024.06×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 25.

Annexed Table 25 Sensitivity analysis of Leping prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-20,586.78	-15,333.37	-13,024.06	-9,664.15	-6,375.28
NPV(Production)	-17,895.9	-15,412.06	-13,024.06	-10,696.03	-8,407.46
NPV(Operation cost)	-10,937.03	-11,969.18	-13,024.06	-14,111.90	-15,179.43

17. Tianfu

Through the economic evaluation of Tianfu prospect，we got the result that the NPV is -7,005.65×10^3 USD when the basic discount rate is 8%, and the NPV will be -18,902.59×10^3 USD when the basic discount rate is 10%, while, the NPV will be -27,779.42×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 26. When there is a great favorable change in price and production, its development can realize a certain economic benefit.

Annexed Table 26 Sensitivity analysis of Tianfu prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-68,669.15	-47,951.24	-27,779.42	-7653.59	12472.10
NPV(Production)	-57,996.85	-42,846.78	-27,779.42	-12745.95	2287.37
NPV(Operation cost)	-17,594.53	-22,686.9	-27,779.42	-32882.27	-37986.71

18. Libixia

Through the economic evaluation of Libixia prospect, we got the result that the NPV is -37,919.70×10^3 USD when the basic discount rate is 8%, and the NPV will be -44,352.03×10^3 USD when the basic discount rate is 10%, while, the NPV will be -49,020.28×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 27.

Annexed Table 27 Sensitivity analysis of Libixia prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-82,771.33	-65,079	-49,020.28	-33,463.23	-18,121.28
NPV(Production)	-73,435.15	-60,883.47	-49,020.28	-37,345.16	-25,885.18
NPV(Operation cost)	-41,081.96	-45,050.52	-49,020.28	-52,991.15	-56,970.46

19. Songzao

Through the economic evaluation of Songzao prospect, we got the result that the NPV is -66,732.51×10^3 USD when the basic discount rate is 8%, and the NPV will be -75,369.03×10^3 USD when the basic discount rate is 10%, while, the NPV will be -81,588.81×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 28.

Annexed Table 28 Sensitivity analysis of Songzao prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-132,847.3	-106,139.9	-81,588.81	-58,413.165	-35634.92
NPV(Production)	-118,760.1	-99,826.04	-81,588.81	-64,251.30	-47074.57
NPV(Operation cost)	-69,834.2	-75,710.13	-81,588.81	-87,637.00	-93865.09

20. Northwest Guizhou

Through the economic evaluation of Northwest Guizhou prospect, we got the result that the NPV is -231,138.33×10^3 USD when the basic discount rate is 8%, and the NPV will be -267,603.97×10^3 USD when the basic discount rate is 10%, while, the NPV will be -294,473.20×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 29.

Annexed Table 29 Sensitivity analysis of Northwest Guizhou prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-437,820.3	-361,892.6	-294,473.2	-231,741.57	-171,345.84
NPV(Production)	-386,588.6	-338,070.5	-294,473.2	-254,763.23	-211,717.44
NPV(Operation cost)	-253,936.6	-271,788.5	-294,473.2	-316,317.90	-338,970.65

21. Guishan

Through the economic evaluation of Guishan prospect, we got the result that the NPV is -26,015.25×10^3 USD when the basic discount rate is 8%, and the NPV will be -33,174.30×10^3 USD when the basic discount rate is 10%, while, the NPV will be -38,574.66×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 30.

Annexed Table 30 Sensitivity analysis of Guishan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-62,017.03	-49,662.03	-38,574.66	-28059.70	-17798.82
NPV(Production)	-53,269.49	-45,590.11	-38,574.66	-31541.54	-24827.80
NPV(Operation cost)	-31,406.01	-35,003.15	-38,574.66	-42264.76	-45742.20

22. Xuanwei

Through the economic evaluation of Xuanwei prospect, we got the result that the NPV is -46,201.85×10^3 USD when the basic discount rate is 8%, and the NPV will be-126,536.96×10^3 USD when the basic discount rate is 10%, while, the NPV will be -187,017.27×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 31. When there is a great favorable change in price, its development can realize a certain economic benefit.

Annexed Table 31 Sensitivity analysis of Xuanwei prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-386,323.7	-283,324	-187,017.27	-93,302.95	1626.94
NPV(Production)	-315,096.1	-251,094.8	-187,017.27	-125,712.81	-62056.78
NPV(Operation cost)	-124,549.1	-155,227.1	-187,017.27	-219,810.81	-250348.90

23. Liupanshui

Through the economic evaluation of Liupanshui prospect, we got the result that the NPV is 101,432.25×10^3 USD when the basic discount rate is 8%, and the NPV will be17,904.35×10^3 USD when the basic discount rate is 10%, while, the NPV will be-45,175.42×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 32. When there is a great favorable change in price and production, its development can realize a certain economic benefit.

Annexed Table 32 Sensitivity analysis of Liupanshui prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-221,066.4	-131,110.8	-45,175.42	40428.27	125,307.51
NPV(Production)	-160,013.5	-101,807	-45,175.42	11792.46	68,035.89
NPV(Operation cost)	12,820.646	-15,815.16	-45,175.42	-74803.89	-102,907.05

24. Xingyi

Through the economic evaluation of Xingyi prospect, we got the result that the NPV is -80,488.39×10^3 USD when the basic discount rate is 8%, and the NPV will be-148,899.37×10^3 USD when the basic discount rate is 10%, while, the NPV will be -200,725.53×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 33.

Annexed Table 33 Sensitivity analysis of Xingyi prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-385,188.62	-289,656.97	-200,725.53	-116,422.16	-30,609.80
NPV(Production)	-320,082.19	-259,838.91	-200,725.53	-143,946.76	-88,092.14
NPV(Operation cost)	-142,856.23	-171,409.16	-200,725.53	-229,847.03	-261,031.14

25. Zhina

Through the economic evaluation of Zhina prospect, we got the result that the NPV is 118,104.24×10^3 USD when the basic discount rate is 8%, and the NPV will be26,351.32×10^3 USD when the basic discount rate is 10%, while, the NPV will be-43,047.13×10^3 USD when the basic discount rate is 12%. It can be seen that it is a marginal prospect. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 34. When there is a favorable change in price and production, its development can realize a certain economic benefit.

Annexed Table 34 Sensitivity analysis of Zhina prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-216,372.89	-129,086.87	-43,047.13	42,200.14	125,817.49
NPV(Production)	-156,330.54	-98,868.71	-43,047.13	13,990.04	69,397.33
NPV(Operation cost)	15,002.96	-13,838.08	-43,047.13	-70,895.28	-99,982.95

26. Guiyang

Through the economic evaluation of Guiyang prospect, we got the result that the NPV is 34,208.29×10^3 USD when the basic discount rate is 8%, and the NPV will be -20,874.84×10^3 USD when the basic discount rate is 10%, while, the NPV will be -62,688.06×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 35. When there is a great favorable change in price and production, its development can realize a certain benefit.

Annexed Table 35 Sensitivity analysis of Guiyang prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-177,141.51	-118,505.95	-62,688.06	-7,279.82	47,161.05
NPV(Production)	-137,846.48	-98,583.80	-62,688.06	-26,237.32	10,546.53
NPV(Operation cost)	-25,556.62	-44,514.13	-62,688.06	-81,466.57	-99,339.15

27. Hongmao

Through the economic evaluation of Hongmao prospect, we got the result that the NPV is 43,795.85×10^3 USD when the basic discount rate is 8%, and the NPV will be 15,196.84×10^3 USD when the basic discount rate is 10%, while, the NPV will be-6,378.18×10^3 USD when the basic discount rate is 12%. It can be seen that it is a marginal prospect. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 36. When there is a favorable change in price and production, its development can realize a certain economic benefit.

Annexed Table 36 Sensitivity analysis of Hongmao prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-57,737.80	-31,406.38	-6,378.18	19,065.57	44,059.59
NPV(Production)	-40,117.95	-23,208.63	-6,378.18	10,633.32	27,195.06
NPV(Operation cost)	10,936.08	2,337.34	-6,378.18	-14,526.48	-23,531.99

28. Luocheng

Through the economic evaluation of Luocheng prospect, we got the result that the NPV is -6,390.00×10^3 USD when the basic discount rate is 8%, and the NPV will be -15,146.35×10^3 USD when the basic discount rate is 10%, while, the NPV will be -21,929.61×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 37.

Annexed Table 37 Sensitivity analysis of Luocheng prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-40,984.33	-31,250.44	-21,929.61	-13,165.67	-4,403.29
NPV(Production)	-34,374.47	-28,042.06	-21,929.61	-16,016.44	-10,475.46
NPV(Operation cost)	-15,900.00	-18,861.61	-21,929.61	-24,968.16	-28,168.15

29. Heshan

Through the economic evaluation of Heshan prospect, we got the result that the NPV is -485,550.03×10^3 USD when the basic discount rate is 8%, and the NPV will be -61,482.73×10^3 USD when the basic discount rate is 10%, while, the NPV will be -71,305.62×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 38.

Annexed Table 38 Sensitivity analysis of Heshan prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-115,111.99	-91,914.59	-71,305.62	-52,527.56	-33,672.66
NPV(Production)	-98,951.10	-85,040.51	-71,305.62	-58,559.29	-46,320.37
NPV(Operation cost)	-58,309.18	-64,825.81	-71,305.62	-78,023.86	-85,320.39

30. Aiweiergou

Through the economic evaluation of Aiweiergou prospect, we got the result that the NPV is -4,180.80×10^3 USD when the basic discount rate is 8%, and the NPV will be -11,759.33×10^3 USD when the basic discount rate is 10%, while, the NPV will be -17,526.25×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 39. When there is a great favorable change in price, its development can realize a certain economic benefit.

Annexed Table 39 Sensitivity analysis of Aiweiergou prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-34,521.68	-257,256.23	-17,526.25	-9,661.06	-1,857.37
NPV(Production)	-28,571.92	-23,025.70	-17,526.25	-12,344.71	-7,122.85
NPV(Operation cost)	-12,246.52	-14,981.18	-17,526.25	-20,357.53	-23,134.67

31. Huolinhe

Through the economic evaluation of Huolinhe prospect, we got the result that the NPV is 11,526.10×10^3 USD when the basic discount rate is 8%, and the NPV will be -53,931.96×10^3 USD when the basic discount rate is 10%, while, the NPV will be -103,163.48×10^3 USD when the basic discount rate is 12%. It can be seen that its development has poor economic benefit. The sensitivity analysis over the parameters of price, production and operation cost is done based on the basic discount rate of 12%, with results in Annexed Table 40. When there is a great favorable change in price, its development can realize a certain economic benefit.

Annexed Table 40 Sensitivity analysis of Huolinhe prospect (10^3 USD)

Change rate	-20%	-10%	0	10%	20%
NPV(Price)	-249,659.96	-172,671.15	-103,163.48	-32,664.85	36,209.49
NPV(Production)	-201,900.67	-151,608.82	-103,163.48	-53,964.73	-6,390.24
NPV(Operation cost)	-59,020.20	-81,091.84	-103,163.48	-123,303.27	-146,017.78