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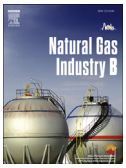

Research article

Strategies for the development of CBM gas industry in China

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Abstract

Since the environment for the CBM development in China has been changing in recent years, it is necessary to re-consider the relevant strategies. Through investigations, surveys, geologic assessment, strategic decision-making and other techniques, the strategies for CBM development in China were discussed in respect to present situations, opportunities, challenges, proved reserves, producing reserves, strategic principles, strategic countermeasures, time-spatial allocation of strategies, risk assessments, and elimination of relevant risks. Some research results were obtained. Firstly, still in its initial development stage with fast growth, the CBM industry in China has made outstanding achievements in six aspects and also faces challenges in six aspects. Secondly, strategic focus can be summarized as constructing six CBM production bases in Qinshui, Eastern margin of Ordos Basin, Southwest China, Changqing, Northwest China, and Northeast China, respectively, according to the principles of "steadily developing middle-high rank coals, accelerating the development of low-rank coals and strengthening the comprehensive utilization of mining gas wells". It is expected that the producing reserves and peak-production rate will be 3–4 trillion m^3 and 35–45 billion m^3/a, respectively. Thirdly, major strategic risks in CBM development in China include low productivities of individual wells, improper understandings of geologic conditions, decline in investments and lack of technical reserves. To eliminate these risks, it is necessary to reinforce work in the following five aspects, namely, strengthening comprehensive exploration and development of coal-bearing formations, creating favorable environments for the development of private oil companies, expanding spaces for the growth of technical service companies, conducting more researches for the development of innovative technologies in more areas and intensifying law enforcement.

Keywords: China; Coal bed methane (CBM); Industry; Development strategy; Producing reserves; Productivity; Production rate; Risk assessment

The CBM area within the buried depth of 2000 m in China is 41.5 × 10^4 km^2 with resources of about 36.8 × 10^{12} m^3 [1]. Since the surface CBM exploration and development started in the 1980s, the CBM industry has experienced exploration period (1987–2000), breakthrough period (2001–2009) and initial period of fast development (2010 to present). At present, two production bases, the Qinshui Basin and the Eastern Ordos Basin, have been constructed. Many researchers expected a promising prospect of the CBM industry in China [2]. However, with the development of shale gas industry, the internal and external environments of the CBM industry in China have changed. Thus, it is very important to study the development strategy of the CBM industry in China in terms of present situations, opportunities, challenges, proved reserves, producing reserves, strategic principles, strategic countermeasures, time-spatial allocation of strategies, risk assessment, and elimination of relevant risks.

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1. Development status and problems

1.1. Development status

The CBM industry in China has made major progress during the 12th Five-Year Plan:

1) Brilliant achievements have been made in exploration and development. ① Comprehensive exploration has been performed in the Qinshui Basin, Eastern Ordos Basin, Southern Sichuan Basin, Xinjiang Uygur Autonomous Region and Northeastern China, consequently contributing to two large gas fields with hundred billion cubic meters of reserves. As of the end of 2014, the cumulative proven reserves have exceeded 6200×10^8 m^3. ② In addition to the development of high-rank CBM resources, the medium-rank CBM resources and the deep CBM resources with Baode Block and Yanchuan South as representatives respectively have also been successfully developed. The annual CBM production rate of China exceeded 37×10^8 m^3/a in 2014, and two CBM industrial bases, Qinshui and Eastern Margin of Ordos Basin, have been established. At present, the third industrial base is being established in the Southern Sichuan Basin [3–6].
2) Downstream market is experiencing diversified development. In addition to pipeline transportation, the downstream market is pluralizing toward domestic fuel, industrial fuel, motor fuel, chemical fuel, power generation, LNG (about 8.4×10^8 m^3/a) and CNG (about 13×10^8–14×10^8 m^3/a).
3) Research and innovation capability has been increasingly improved. By far, 15 CBM national projects and 6 demonstration projects are under research [7], which has effectively enhanced the research and development strength of the CBM technology of China. A number of colleges and universities are also training CBM professionals.
4) Industrial development mechanism has been perfected: The No.93 Document issued by the State Council of People's Republic of China and the "policy of CBM industry" issued by the National Development and Reform Commission and National Energy Administration of People's Republic of China have supplemented and improved the policies of the CBM industry in China. In actual operation, three aspects are well implemented, including VAT levying first and refunding later, development subsidy and mining right management.
5) Coal mine safety situation is getting better. The mortality rate of the coal mine has decreased from 1.966 in 2006 to 0.245 person in 2014 per ten thousand tons of raw coal.
6) CBM development has certain economic benefits. Some companies have already made profit and situations of other enterprises are turning better too.

1.2. Major problems

With rapid development, the CBM industry in China is facing some problems.

1) Development speed. At present, most CBM production of China is in the Qinshui Basin and the Eastern Margin of the Ordos Basin, accounting for 94.6% of the total production rate in 2014. Therefore, some studies suggest that the development of China's CBM industry is too slow to meet the country's demand for clean energy.
2) Resources. The gas pools with poor quality, great burial depth, low gas content and low permeability take a considerable proportion. The proven reserves with a burial depth of more than 900 m account for 29%. The proven reserves of high-rank coal with a gas content of 15–20 m^3/t only account for 65% and the proven reserves of high-rank coal with a permeability of less than 0.1 mD account for 35%.
3) Development program and development technology. Most CBM development programs of China are "copied" ones from the development program of conventional oil and gas fields, while the development technologies are "transplanted" ones from foreign development technology, thus, there come some problems such as impertinent development programs and poorly applicable development technologies [8–11].
4) Pipeline and transportation. Some CBM production regions lack CBM pipelines, as a result, some CBM already developed is unable to enter market and is forced to vent out.
5) Development investment. Restricted by low CBM price, long payback period and insufficient proven reserves, the CBM development investment in China is limited, so it is difficult to complete the task of national planning [2].
6) System and mechanism. ① The system is imperfect, involving problems such as complex benefit distribution system, mining right overlapping, much land use and complex relationship between industry and agriculture. ② In terms of development mechanism, some policies are of too principle, some policies are poor in operability, and local governments are not so positive in the development of CBM.

2. Opportunities and challenges

2.1. Opportunities

1) The energy security of China has been raised to an unprecedented level. In June 2014, the Central Financial Work Leading Group pointed out that "it is necessary to strengthen the exploration and development of oil and gas, strengthen the establishment of oil and gas pipelines and storage facilities, improve energy emergency system and capacity building and improve energy statistical system [12]" in the sixth meeting when examining

China's energy security strategy, raising energy security to an unprecedented level;

2) Chinese government attaches great importance to air pollution control and green energy development. On 17 September 2013, six departments of the People's Republic of China, including the Ministry of Environmental Protection National Development and Reform Commission etc jointly issued the "implementation details of air pollution prevention and management action plan of Beijing, Tianjin and the surrounding areas" [13], which requires that the concentration of fine particle matter (PM2.5) of around Bohai Bay area including Beijing, Tianjin and Hebei Providence be decreased by 25% from that of 2012 by 2017, that of Shanxi Providence (major coal producing and CBM producing providence) be decreased by 20%, and that of Inner Mongolia Autonomous Region (present major coal producing providence and future CBM producing providence) be decreased by 10%, which provides an important opportunity for the development of CBM in China.
3) The rapid development of natural gas industry has created favorable conditions for the development of CBM industry: BP Company predicted that during 2010–2030, China's natural gas demand would grow rapidly at an average annual growth rate of 7.6%, in 2030, the consumption of natural gas would reach 4870×10^8 m^3/a and the import demand for natural gas would reach 40% [14]. Under the challenge that conventional oil and gas production is difficult to increase, developing unconventional oil and gas resources including CMB is a realistic choice for sustainable energy development in China.
4) The construction of Sino-Russian gas pipeline has created new opportunities for the development of CBM. According to the contract of "Sino-Russian east gas cooperation project memorandum" signed between Chinese and Russian government (with contract total value of about US$ 400 billion, period of 3 decades and annual supply of 380×10^8 m^3/a) [15], the Sino-Russian agreed specific price may be at around 2.19 Yuan/m^3, which is higher than domestic CBM sale price, thus, there is still great space for further CBM development.

2.2. Challenges

1) Shale gas development has a certain impact on CBM development. Since 2008, Sinopec began to get involved in the field of shale gas [16] and made significant progress in the exploration of shale gas in Sichuan and Chongqing in 2013; in 2014, PetroChina set up shale gas front headquarters in Sichuan and Chongqing in order to coordinate the exploration and development of shale gas, and deputy general manager of CNPC held the post of team leading, representing a rarely-high standard in recent years; shale gas has gradually replaced the leading position of CBM in unconventional gas and become the major investment target for domestic unconventional gas.
2) Development investment shows a downward trend. Since 2013, the investment of CBM in China has shown a decline trend. From 2011 to 2014, the new CBM wells drilled in China were 3100, 4000, 1900 and 1200 in numbers respectively. Since the second half of 2014, influenced by the slump of international oil price, the income of the three large oil companies declined, resulting in further negative impact on the development investment of CBM;
3) Investment environment still needs to be improved. The development of CBM is characterized by small well space, dense well pattern and extensive land use. Thus, land use approval has already become an important problem hindering the capacity building speed. The investment environment of CBM exploration and development still needs to be improved since the phenomena of multi-leader and multi-level management, repeat approval, imperfect, offside and vacancy management exist.

3. Prospect selection and prediction of proved reserves and producing reserves

3.1. Prospect selection

Firstly, CBM enrichment zones (plays) are selected with three steps (gas basin scale selection, screening of block area-resource abundance combination and screening of gas content key element), and 19 CBM enrichment zones (plays) have been selected; then, the 19 zones (plays) are further divided into Class I, II and III according to the parameters of the zones (plays), such as coal rank, burial depth, thickness, permeability, porosity, coalbed gas content and reserves abundance: there are five Class I zones, which are the most prospective zones suitable for exploration and development in priority, with resources of 2.8×10^{12} m^3; there are six Class II zones, which have similar resource abundance with Class I zones, but have smaller gas-bearing area, with resources of 4.7×10^{12} m^3; there are eight Class III zones, which have poor resource abundance, but have a certain exploration and development potential, with resources of 1.5×10^{12} m^3. The resources of the three classes of zones have total resources of 9.1×10^{12} m^3 (Table 1).

3.2. Prediction of proved reserves and producing reserves

With the development block of the Qinshui Basin with completed exploration and development data as calibrated unit, the proved reserves and producing reserves of the basin were analyzed firstly. The proved rate of CBM within 1200 m and between 1200 and 2000 m in burial depth are 70% and 60% respectively, and the producing degree of proved reserves in Fanzhuang, Zhengzhuang and Mabi Block is 50%–70%.

Table 1
Prediction of proved CBM reserves and producing CBM reserves in China.

Class	Block (Play)	Burial depth of major coal bed/m	CBM resources (10^8 m^3)	Predicted proved reserves (10^8 m^3)	Predicted producing reserves (10^8 m^3)
I	Southern Qinshui Basin	200–1200	8900	6230	3730
	Eastern Ordos Basin	300–1500	11485	7440	4310
	Yangquan-Heshun	300–1000	6448	4190	2430
	Gulin, Xuyong	300–1200	1000	650	370
	Yinggangling in Pingle	800–1500	214	130	70
II	Huolinhe	150–1500	1025	660	360
	Xixiagou in Santanghu Basin	600–1500	2170	1300	680
	Southern Tarim	300–1500	15700	9420	4990
	Yili	500–1500	5912	3540	1870
	Wushenqi	300–1500	17000	11050	6070
	Changji-Fukang	800–1200	5600	3640	2000
III	Huangling-Binxian Changwu	300–1500	1435	780	370
	Huhehu	600–1500	1325	720	340
	Boli	500–1500	3100	1700	850
	Jixi-Hegang	350–1500	1533	840	400
	Panguan	800–1200	1900	1040	490
	Hengshanbao	400–1500	2203	1210	580
	Shenmu	500–1500	2281	1250	600
	Southern Ningwu	300–1500	1665	910	430
Total			90896	56700	30940

Then, the reservoir parameters were calculated by cluster analysis statistical method by using SPSS software, the results show that the 19 prospective zones have proved reserves of 5.673×10^{12} m^3 and producing reserves of 3×10^{12} m^3 (Table 1). Influenced by the five factors, including the increase of producing level of proved reserves, the integrated exploration and development of coalbeds, the development and utilization of the CBM resources of coal resources exhausted mine, the progress of tectonic coal development technology and the exploration and development of deep CBM, the producing reserves of the CBM in China will increase to possibly more than 4×10^{12} m^3.

4. Development strategy of CMB in China

4.1. Strategic principle

It is important for the CBM industry in China to adhere to three "developments" and construct six regional "industrial bases."

4.1.1. Three "developments"

Three "developments" refer to "steady development of medium–high rank CBM, faster development of low-rank CBM, and deeper development of comprehensive utilization of the resources in wells".

① Based on the two CBM industrial bases constructed in the "12th Five-year Plan", the development of the third industrial base in medium–high rank coal (Southwest China) should be strengthened, and the exploration and development of the CBM in medium–high rank coal, such as Ningwu Basin, Jiaozhuo and Pingdingshan in Central China should be promoted steadily. ② The development of low-rank coal blocks should be accelerated, including Fuxin, Tiefa, Jiergalangtu, Boli, Jixi and Hegang in Northeastern China and Junggar Basin, Tuha Basin and Santanghu Basin in Northwestern China, which have advantages of large coal bed number, great coal bed thickness, high resource abundance and permeability, but have disadvantages of low gas content and high water production rate; at present, except some small mines, such as Fuxin and Tiefa have been put into development, most mines are still in their initial exploration phases, so their exploration should be accelerated, and the research on enhancing individual well production should be strengthened. ③ The comprehensive utilization of resources in wells should be strengthened. It is proposed that the gas transmission and distribution systems of large mines be connected by regional networks to realize centralized and scale utilization. In middle-small coal mines, scattered small power plants should be constructed or pipe networks and centralized electricity-generation plants should be constructed jointly in order to improve utilization ratio.

4.1.2. Six "CBM production bases"

The six regional "CBM production bases" include Northeast China, Qinshui, eastern margin of Ordos basin, Central China, Southwest China and Northwest China.

Besides the Qinshui Basin, the Qinshui CBM production base also includes Ningwu, Datong etc. small basins in the northern Shanxi Province, which is the key area for the CBM productivity construction of the "11th Five-year Plan" and "12th Five-year Plan". By the end of 2014, its cumulative proved reserves had exceeded 4600×10^8 m^3, and cumulative productivity had exceeded 40×10^8 m^3/a; its annual production rate was about 30×10^8 m^3/a in 2014, its maximum cumulative producing reserves are expected to reach 8000×10^8 m^3 and its cumulative productivity is expected to

be 140×10^8–160×10^8 m^3/a. It is a key to the productivity construction in the "13th Five-year Plan".

The Eastern margin of Ordos Basin CBM production base is a key to the productivity construction in the "12th Five-year Plan". By the end of 2014, it had cumulative proved reserves of about 1500×10^8 m^3, cumulative productivity of over 15×10^8 m^3, and annual production rate of about 6×10^8 m^3/a in 2014. It is expected that it will reach the ultimate cumulative producing reserves of 5000×10^8–5500×10^8 m^3 and cumulative productivity of 100×10^8–110×10^8 m^3/a, making it a key base of productivity construction in the "13th Five-year Plan" period.

The exploration and development in the Southwest China CBM production base (also known as South Sichuan-East Yunnan and West Guizhou CBM production base) mainly concentrate in Junlian and Xuyong regions, among which, the proved reserves of Junlian block will exceed 200×10^8 m^3, providing the resource base for constructing the productivity of 5×10^8 m^3/a. In 2013, the productivity construction of 2×10^8 m^3/a started there; this production base is the main battlefield of the CBM productivity construction in the "13th Five-year Plan" in China, which is expected to have cumulative producing reserves of 2500×10^8–3000×10^8 m^3 and cumulative productivity of 50×10^8–60×10^8 m^3/a.

In Central China CBM production base (also known as Changqing CBM production base) targeting Mesozoic Jurassic Yan'an Formation, the CBM exploration began early in 1994, and horizontal well DFS-02 put into production in 2010 in shaanxi Binchang area had a maximum gas production of over 1.6×10^4 m^3/d. This base is expected to reach cumulative producing reserves of 6000×10^8–9000×10^8 m^3 and cumulative productivity of 120×10^8–180×10^8 m^3/a.

Northeast China CBM production base, including the three northeastern provinces and Inner Mongolia region, is a key area of productivity construction after the "13th Five-year Plan". The production of the exploration wells in Hunchun Block of Jilin Province and Yilan Block of Heilongjiang Province has reached over 1.5×10^3 m^3/d. Fuxin and Tiefa have been put into production, with a daily productivity of about 12×10^4 m^3/d. This base is expected to reach cumulative producing reserves of 3000×10^8–4000×10^8 m^3 and cumulative productivity of 60×10^8–80×10^8 m^3/a.

Northwest China CBM production base with low exploration and development degree includes Gansu, Qinghai, Xinjiang Uygur Autonomous Region and the three basins in Xinjiang (Tarim, Junggar and Tuha Basins), which will be the major productivity construction area for the CBM development in China after the "13th Five-year". The gas production of Well CSD01 in Fukang coal mine developing area of the Junggar Basin reaches 1.7×10^4 m^3/d. As for the three basins in Xinjiang, the cumulative producing reserves are expected to be 6000×10^8–9000×10^8 m^3 and cumulative productivity is predicted to be 120×10^8–180×10^8 m^3/a. As for Yuka and Dameigou in Qinghai Province, the cumulative producing reserves are predicted to be 500×10^8–1000×10^8 m^3 and cumulative productivity is predicted to be 10×10^8–20×10^8 m^3/a. As for Wuwei, Chaoshui Basins in the western Gansu Province, the cumulative producing reserves are predicted to be 300×10^8–500×10^8 m^3 and cumulative productivity is predicted to be 6×10^8–10×10^8 m^3/a.

The cumulative producing reserves in the six CBM production bases above are predicted to be 3×10^{12}–4×10^{12} m^3 and cumulative productivity is predicted to be 600×10^8–820×10^8 m^3/a, peak production is expected to reach 350×10^8–450×10^8 m^3/a. The gas production profile is shown in Fig. 1.

4.2. Strategic countermeasures

The development countermeasures for the CBM industry of China include doing good job in "One leading", "Two encouraging" and "Five combining". "One leading" refers to give full play to the technical leading role of the three large oil companies and the scientific and technological strength of the original coal departments (such as Coal Science and Industry Group of China, Research Institute of Coal Information). The "Two encouraging" refers to ① encouraging oil and gas companies to serve in coal mine especially coal mining area to extract gas; ② encouraging private capital financing of mixed private ownership. "Five combining" refers to ground surface combining with downhole, nearby utilization combining with export, safety and environmental protection combining with development, self-run combining with cooperation, basic research combining with innovation.

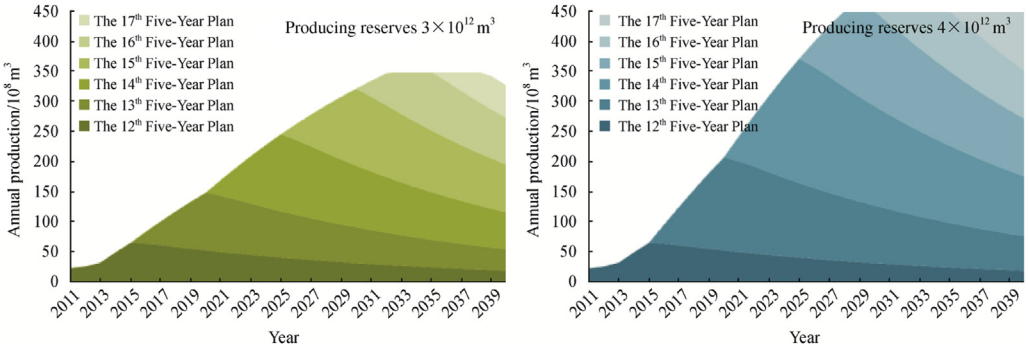

Fig. 1. Strategic planning of the CBM producing profile of China.

4.3. Strategic time arrangement

From 2016 to 2020 (the 13th Five-year Plan Period), the exploration will focus on Qingyang-Huangling and Wushenqi in Central China, Jiergalangtu of Mongolia exploration area in Northeast China, Jixi and Hunchun in Heilongjiang exploration area, meanwhile, the exploration of Xinjiang low-rank CBM should be strengthened. In terms of development, three CBM production bases will be constructed (Qinshui, the Eastern margin of Ordos Basin and Southwest China).

During 2021−2025 (the 14th Five-year Plan Period), the exploration of Xinjiang low-rank CBM will be strengthened, meanwhile, the construction of the CBM production base of Central China and Northeast China will be fully completed.

During 2026−2030 (the 15th Five-year Plan Period), new CBM replacement will be searched and exploration will be extended to deep layers, meanwhile, the construction of the CBM production base of Northwest China will be fully completed.

4.4. Strategic risk assessment

Strategic risk assessment includes the assessment on the risk of individual well production, geological recognition, input decline and insufficient technological storage.

1) Risk of individual well production: The average individual well production of the CMB in China is about 1000 m^3/d at present, the benefit and investment economy of the CBM development of China will be inevitably influenced if the individual well production keeps low for a long time.
2) Risk of geological recognition: Xinjiang region and the central Ordos Basin are the major areas for conventional oil and gas exploration and development of the three large oil companies and Yanchang Oilfield, where investment on CBM exploration and development is small and little understanding has been obtained.
3) Risk of investment decline: Affected by the slump of international oil price, the development investment of CBM is declining.
4) Risk of insufficient technological storage: At present, the major object for CBM exploration and development in China is high-rank coal, which will shift to medium−low rank coal with multiple layers, large thickness, low gas content and high water production in the future, thus, innovations in drilling and completion technology, stimulation technology are needed to cope with the CBM exploration and development of this kind of coal.

4.5. Avoidance of the risk in CBM strategy

1) Changing thought and conducting comprehensive exploration and development of coal measure strata. Compared with major CBM production nations such as the United States and Australia, China faces more complex geological conditions, lower individual well production, slower capital recovery rate and poorer economic benefit in the development of CBM; in fact, the CBM industry of America is not limited in the exploration and development of "coal bed", but includes the exploration and development of the tight sandstone gas and argillaceous sandstone gas in the entire coal measure strata. Thus, relevant departments should introduce policies to encourage the integrated exploration and development of coal measure strata.
2) Creating an environment suitable for the development of private oil companies. In addition to some large companies, such as Exxon-Mobil and BP, the companies that lead to the development of CBM industry are all small companies, such as Australian Arrow Company, American Far East Company, which have flexible management and need small investment to construct the productivity of equal scale, thus, they are more likely to make profit in the exploration and development of CBM. Therefore China should appropriately lower the permission threshold of CBM companies, grant CBM exploration and development mineral right permit to private companies with strength and encourage private capital to enter CBM industry.
3) Opening market and increasing the development space for CBM technology service companies. The core factor for the development of CBM industry is technology, for example, the pinnate horizontal well technology of the BHP Company of the U.S. has promoted the high-efficient development of the San Juan Basin. Thus, China should continue to open the market, avoid local and enterprise protection and encourage CBM technology service companies with strength to enter CBM market.
4) Expanding scientific and technological research. In addition to the scientific and technological research of conventional CBM development and utilization, the following four new fields should be positively researched: ① development and utilization of the CBM resources in coal resource depletion mines; ② development and utilization of structural CBM; ③ development and utilization of CBM in deep coal beds; ④ development and utilization of "biological CBM".
5) Seriously implementing relevant laws and regulations: From a resource point of view, it is an indisputable fact that China has abundant CBM resources, however, some powerful CBM enterprises have gradually decreased backup blocks, while other CBM enterprises having mining rights of some blocks don't start exploration or development. From a policy point of view, although China has a lot of laws and regulations supporting CBM exploration and development, but they are not implemented well; from an investment environment point of view, the investment environment for CBM should be improved. Thus, relevant departments need to implement relevant laws and regulations stringently, so as to promote the development of CBM industry.

5. Conclusions

1) The CBM industry in China is still at its initial stage of rapid development, and is facing development and difficulties, and opportunities and challenges at the same time;
2) The overall principle for the CBM development in China is to adhere to the principle of "steadily developing high-rank coals, accelerating the development of low-rank coals and strengthening the comprehensive utilization of the resources in the well" and constructing six regional "production bases", including Qinshui, Eastern margin of Ordos Basin, Northeast China, Changqing, Northeast China and Northwest China. The development goal is cumulative producing reserves of 3×10^{12}−4×10^{12} m^3 and peak production of 350×10^8−450×10^8 m^3/a.
3) The strategic risks of CBM in China are low individual well production, poor geological recognition, declining investment and insufficient technological storage, which should be avoided from five aspects, including strengthening comprehensive exploration and development of coal-bearing formations, creating favorable environment for the development of private oil companies, expanding space for the growth of technology service companies, expanding researches for the development of innovative technologies in more areas and intensifying law enforcement.

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