INTRODUCTION

Globally, Coalbed Methane (CBM), including coal mine methane (CMM) captured from the underground mining operations, is attracting growing attention mainly from the perspective of climate change caused by greenhouse gas (GHG) emissions. However, China has two additional and very compelling reasons for addressing the issue—decreasing coal mining accidents and developing cleaner energy resources to improve air quality in cities.

China’s domestic natural gas production has been growing rapidly in recent years, but its growth rate still cannot catch up with the increasing consumption rate. From 2006 to 2016, China’s natural gas production increased from 60.6 billion cubic meters (bcm) to 138.4 bcm at an annual rate of 8.6%, while its consumption increased from 59.3 bcm to 210.3 bcm over the same period at an annual rate of 13.5%. Both rates are far higher than the world’s natural gas consumption growth rate of 2.3% over the same period. In 2016, China imported 71.9 bcm of gas to offset its domestic natural gas shortage.
implying an import dependence of 34.2%. Moreover, China is projected to provide a quarter of the rise in global gas demand, and the projected import is estimated to be 280 bcm in 2040; this will make China a linchpin of the global gas trade, only behind the European Union. Therefore, the supplementation of unconventional gas, such as CBM, is especially important because CBM is an important type of natural gas and has a large reserve in China.

The government of China is actively promoting the development and utilization of CBM to meet the growing energy demand, improve the safety of mining operations and achieve significant reductions in China’s greenhouse gas (GHG) emissions. In 2012, the total CMM emission volume was 55.92 Mt (1.17 Bt CO2 equivalent), accounting for 9.9% of the total GHG emissions in China. Among these, 27.59 Mt was from energy, accounting for 49.3% of the total CH4 emission. Therefore, more CH4 must be captured rather than released from coal mines. Meanwhile, the government has made GHG emission reduction targets by 2020, including reducing the intensity of CO2 emissions by 40%-45% from the 2005 level, reducing the CO2 emissions per unit of GDP by 18% from the 2015 level, and making efforts to reduce CH4 emissions from energy activities. China has made this progress by decreasing its reliance on coal, increasing investments in clean energy, and shifting its economy away from heavy industry and toward services, among other actions.

However, to achieve these targets, the government must improve the administrative framework for CBM resource management, introduce more effective CBM development incentives, raise the technical capacity of the mining sector, expand gas pipeline infrastructure, and promote gas markets in coal mining areas.

The CBM exploration and development in China experienced four main stages. During the first stage (preparation stage, 1952-1989), the underground gas drainage activities appeared, and coal mines started to measure the gas content and adsorption abilities of coal. In the 1970s, the commercial development of CBM in the United States gassy basins, such as the Black Warrior, San Juan, and Powder River, attracted much attention from China’s oil industries and the academia and triggered geological studies focused on the CBM resources in China. The research outcomes provided important fundamentals for the further evaluation of China’s CBM resources and the investigation of favorable zones. The second stage is the learning stage (1990-1995). Some professional facilities and commercial software were brought to China, and professionals actively participated in corporations with experts from other countries. These efforts quickly improved the techniques to evaluate CBM resources, measure the formation properties and produce gas from wells. In this stage, the exploration and development of CBM started to be implemented in China. In the third stage (forward stage, 1996-2005), to promote the development of the CBM industry in China, the Ministry of Science and Technology established many research and testing projects that focused on ways to improve the methodologies to evaluate and optimize the advantageous blocks, clarify the enrichment of CBM and analyze the controlling factors influencing gas production. Meanwhile, according to some successful and important drilling and exploration accomplishments, many trial research projects were established as well. At the current stage (innovation stage, from 2006 to present), two large CBM production areas, Qinshui Basin and eastern Ordos Basin, were successfully established. Many theoretical achievements were made in aspects including CBM accumulation, CBM geology, and stimulation and production techniques, which provide support for the development of new techniques to promote CBM production. Some methodologies to dynamically evaluate the CBM reservoir, select sweet spots, and optimize production strategies have been established as well, which supports the commercial production of CBM in China. In this stage, the gas industry in China pays significant attention to the development of innovative techniques and the theories of the exploration and development of CBM in China.

Over the past 25 years, China has devoted to develop its substantial CBM resources. Despite China’s long-going efforts, CBM well productivity in China is still significantly lower than that in some other countries, such as Australia and the United States. On the one hand, it depends on the geological conditions for CBM development; on the other hand, the development strategy and management of the CBM industry are more important. A unique combination of favorable geology, a mature gas market, strong demand, good prices, and well-developed pipeline infrastructure enabled the United States and Australia to establish significant CBM production. Although the support to the CBM industry in China is increasing every year, and some policies have been supplemented every year as well, the incomplete policies have seriously hindered the rapid development of CBM industry in China. The government needs to provide specific incentives to stimulate development as in the United States and Australia. The current study analyzed the problems and common restrictions existing in the development of China’s CBM industry and proposed suggestions to improve it.

2 | CURRENT STATUS OF CBM RESOURCES EVALUATION AND DEVELOPMENT IN CHINA

The latest round of China’s oil and gas resources evaluation performed by the China National Petroleum Corporation (CNPC) is presented in Table 1. The total gas-in-place of China’s CBM resources buried shallower than 2000 m is estimated at 29.8 trillion cubic meters (tcm) and the technically recoverable resource is approximately 12.5 tcm. Compared
to the estimated results in 2006, the total CBM resource is reduced by 7 tcm; however, the technically recoverable resource is increased by 1.6 tcm, indicating improved resource evaluation accuracy and reliability. As shown in Figure 1, the CBM is mainly distributed in four gas regions in China (Northeast, Northwest, North, and South China), and CBM

| Region               | Basin/area                          | Coal age | Coal resources ($\times 10^8$ t) | Evaluation area (km$^2$) | Geological resources (bcm) | Recoverable resources (bcm) |
|----------------------|-------------------------------------|----------|---------------------------------|--------------------------|----------------------------|----------------------------|
| Northeast China      | Sanjiang-Mulinghe                   | K$_1$    | 273.15                           | 2565.03                  | 310.34                     | 5.34                       |
|                      | Songliao                            | K$_1$    | 5.65                             | 601                      | 3.93                       | 0.51                       |
|                      | Yilan-Yitong                        | E        | 5.56                             | 54.46                    | 5.25                       | 1.21                       |
|                      | Yanbian                             | E        | 10.22                            | 135.63                   | 2.91                       | 0.70                       |
|                      | Dunhua-Fushun                       | E        | 24.06                            | 198.22                   | 10.98                      | 5.66                       |
|                      | Hunjiang-Hongyang                   | C-P      | 63.1                             | 1196.31                  | 118.64                     | 68.36                      |
|                      | Liaoxi                              | J$_3$    | 21.04                            | 155.52                   | 16.22                      | 12.55                      |
|                      | Hailaer                             | J$_3$    | 4797.67                          | 12986.09                 | 1296.86                    | 756.15                     |
|                      | Erlian                              | J        | 6819.69                          | 34853.62                 | 1181.70                    | 447.54                     |
|                      | Yinshan                             | J        | 98.25                            | 436.47                   | 81.77                      | 14.95                      |
|                      | **Total in Northeast China**         |          | 12 118.39                        | /                        | 3028.60                    | 1361.00                    |
| North China          | Yuxi                                | C-P      | 368.88                           | 5923.51                  | 674.41                     | 175.70                     |
|                      | East foot of Taihangshan            | C-P      | 246.92                           | 2245.18                  | 431.42                     | 76.70                      |
|                      | Xuhuai                              | C-P      | 721                              | 3490.66                  | 578.46                     | 242.91                     |
|                      | Jizhong                             | C-P      | 164.45                           | 937                      | 177.33                     | 76.11                      |
|                      | Jingtang                            | C-P      | 117.64                           | 700.35                   | 141.87                     | 52.55                      |
|                      | Northern Henan-Northwestern Shandong| C-P      | 171.97                           | 4081.41                  | 118.07                     | 17.95                      |
|                      | Qinshui                             | P, C     | 2448                             | 53 049                   | 4000.39                    | 1525.64                    |
|                      | Datong                              | P$_{1s}$, C$_{3}$ | 314.77     | 948.25                  | 142.81                     | 47.06                      |
|                      | Ningwu                              | P$_{3s}$, C$_{t}$ | 377.18      | 1718.67                  | 364.36                     | 180.77                     |
|                      | Ordos                               | J, C-P   | 14 504.69                        | 132 177.9               | 7259.91                    | 2795.91                    |
|                      | **Total in North China**             |          | 19 435.5                         | /                       | 13 889.03                  | 5191.30                    |
| Northwest China      | Junggar                             | J$_{1,2}$ | 5290.87                          | 26 126                   | 3108.77                    | 1361.50                    |
|                      | Tuha                                | J        | 4479.55                          | 13 318                   | 1164.43                    | 653.18                     |
|                      | Santanghu                           | J        | 937.3                            | 4695                     | 318.18                     | 181.24                     |
|                      | Tarim                               | J$_{jk}$, J$_{yy}$ | 1098.95    | 5877.13                  | 1297.27                    | 595.95                     |
|                      | Qaidam                              | J        | 165.78                           | 1229.68                  | 141.18                     | 79.82                      |
|                      | Gansu corridor                      | P$_{1}$, J$_{2}$, C$_{3}$ | 441       | 5626                     | 117.20                     | 58.16                      |
|                      | Tianshan                            | J$_{1,2}$ | 4821.11                          | 20 632                   | 1626.15                    | 896.83                     |
|                      | **Total in Northwest China**         |          | 17 234.55                        | /                       | 7773.18                    | 3826.69                    |
| South China          | Sichuan                             | P, T     | 608.63                           | 19 684.57                | 604.21                     | 271.75                     |
|                      | Eastern Yunnan-Western Guizhou      | P$_{2}$  | 2658.28                          | 16 055.15                | 3472.38                    | 1405.24                    |
|                      | Leping                              | P, T     | 27.19                            | 509.31                   | 33.97                      | 14.96                      |
|                      | Southern Sichuan-Northern Guizhou   | P$_{2}$, T$_{3}$, C$_{1}$ | 672.31      | 11 007.28               | 1009.94                    | 438.34                     |
|                      | Central Guangxi                     | P$_{2}$, E, C$_{1}$ | 6.72      | 384.7                   | 9.86                      | 4.92                       |
|                      | **Total in South China**             |          | 3973.13                          | /                       | 5130.35                    | 21 352.05                  |
|                      | **Total in China**                  |          | 52 761.58                        | /                       | 29 821.16                  | 12 514.19                  |
resources are relatively concentrated and mainly associated with large basins (basin groups) in five stratigraphic strata (Carboniferous-Permian and Jurassic in North China, Permian in South China, Jurassic in Northwest China, and Jurassic-Cretaceous in Northeast China). Among them, the CBM resources in North China account for 46.6% of the total resources, and the resources in Qinshui and Ordos Basins account for 37.8%.

Figure 2 shows that during the “12th Five-Year Plan” (2011-2015), more than 11,300 production wells were drilled, and the new proven geological reserves were improved to 350.4 bcm, representing an increase of 193.3% in China’s production wells and an increase of 77% in its reserves. In 2015, the ground production of CBM was approximately 4.4 bcm, and the utilized amount was 3.8 bcm, representing increases of 193.3% and 216.7% compared with the figures in 2010 and annual increasing rates of 24.0% and 25.9%, respectively. In 2015, the CMM extraction was 13.6 bcm, and the utilized amount was 4.8 bcm, representing increases of 78.9% and 100% compared with the amounts in 2010 and annual increasing rates of 12.3% and 14.9%, respectively. The utilization rate of CMM is 35.3%, increasing 3.7% compared with that in 2010. Thus, China’s coalbed methane has achieved rapid development in the past five years. However, the current CBM production rate is still far lower than that expected by the government (the expected ground production was 16 bcm, and the expected underground extraction was 14 bcm in 2015).

3 | GENERAL PROBLEMS OF CHINA’S CBM INDUSTRY

At present, China’s CBM industry is still in its infancy, with a relatively low level of development. In addition to the complex geological conditions and production technologies, other constraining factors, including conflicting mining rights, insufficient pipeline networks, difficulties in utilization, insufficient subsidies, imperfect gas markets, and difficulties in attracting private capital, result in high CBM production costs and low returns. Since 2013, due to
the global energy market and policies, investment in CBM exploration and development has slowed down, and there has been a large gap between CBM ground production and CMM utilization and the 12th Five-year Plan targets. The contradictions and problems that hamper development must be solved.36-42

3.1 | Exploration and development technology need a breakthrough

Compared to those in other countries,43-53 coal seams in China have low formation pressure, low permeability, and low gas saturation.54-59 High-stress blocks,60 tectonic coal blocks,61,62 ultralow permeability coal blocks,24,63 and deep difficult-to-recover coal blocks64,65 account for over 75% of the total resources and cannot be effectively produced using conventional techniques in China.66-68 For many years, the implementation of science and technology support projects such as the national “863” plan, the “973” plan, the high-tech industrialization demonstration projects, and the National Science and Technology Major Projects have resulted in the development of a number of scientific and technological achievements, and the results of these projects have solved some problems in the exploration, development, transportation, and utilization of normal CBM. However, in view of the high proportion of various types of difficult-to-recover CBM resources in China, geological theories in CBM generation, seepage, and development to meet China’s geological conditions have not yet been established, and thus far, no breakthroughs have been made in fundamental theory and technology. The average single-well production of CBM wells in China is low and cost-ineffective.63,69 The internal cause of the inefficient upstream development of CBM is mainly due to the outdated techniques. Currently, the evaluation and exploration techniques in areas of CBM concentration, low-rank CBM exploration and development techniques, high-efficiency drilling and completion technologies, stimulation technologies, gathering and transportation, and processing or utilization techniques for CBM require in-depth research.

3.2 | Mining conflicts between CBM fields and coal mine fields

The overlap of coal mining rights and CBM production rights has always been a major factor restricting the development of the CBM industry in China, which involves conflicts of interest between national and local enterprises. In 1998, with the reform of government institutions, the Former Ministry of Coal Industry (FMCI) was dissolved, and its functions were assigned to the Ministry of Land and Resources of China (MLRC), while the MLRC requested the reregistration of CBM mining rights. Enterprises that had coal mining rights before 1998 were not reregistered due to operational

FIGURE 2 Variation of CBM proven reserves, wells, and production (ground development) in China

FIGURE 3 Energy consumption structure of China and the world in 2017 (data are from BP72)
difficulties or lack of awareness of resources. As a result, unregistered CBM mining rights were recovered by the MLRC and were subject to its first-level management. This resulted in the overlapping of mining rights for the same block.

Figure 3 shows that coal accounted for 60.42% of the total fuel consumption in 2017, which is much higher than the world average (27.62%). Due to the dominant position of coal in China's energy structure, there is a policy of “first produce coal, then produce gas” or the repulsion of CBM prospecting rights in some coal-producing areas, which places CBM rights to a low level. The overlap of CBM and coal mining rights directly affects the large-scale development and utilization of CBM. Conflicts between CBM development and coal or oil development have gradually emerged. CBM is an unconventional natural gas, that is, associated with coal and stored in an adsorbed state. Coal mining and gas extraction must be combined systematically to achieve coordinated development. Otherwise, not only will resources be wasted and the environment polluted, but coal mine safety will also be threatened. According to the General Office of the State Council's “Several Opinions to Accelerate the Use of CBM (CMM) Drainage,” the state promotes the integration of coal mining and gas extraction. However, when this specific requirement was implemented, it was difficult, and there was a phenomenon of segregation of gas from coal mining. Due to the separation of CBM rights and coal mining rights and the incompatibility of these two resources, the scientifically based, rational and safe integrated deployment of gas production and coal mining may not be achieved at both the time and space scales.

### 3.3 Insufficient management system

In China, CBM exploration and development management responsibilities are not clear, leading to long and complex CBM project approval management procedures. Some CBM projects have been disputed in the implementation process. Additionally, companies that develop and utilize CBM concentrate too much on their own benefits and normally lack communications. There is no authoritative data, which makes it difficult for the government to manage the CBM industry on a macroeconomic scale. How to reasonably arrange the property rights of CBM resources, how to achieve the optimal allocation of resources, and how to effectively manage the CBM resources to ensure the orderly implementation of CBM projects have become the primary issues facing the CBM industry in China.

Since the 1990s, China has established a number of CBM development companies. These companies have done much work to extend the external cooperation, self-exploration and development of local CBM, develop theory and technologies on CBM exploration and development and formulate standards and regulations, etc. Active and effective work has laid a good foundation for the large-scale commercial development and utilization of CBM. However, due to the state's macro-management and other reasons, in terms of both funding and implementation, the state's support for CBM companies is not enough, resulting in unsatisfactory overall development. Due to the large constraints of the state management system, since the establishment of the national CBM companies, institutional problems have not been well resolved, thus hindering the smooth development of the CBM industry. Limited to institutional factors, no scientific solution has been found to effectively address investment enthusiasm and market development.

### 3.4 Economic support is decreasing

The release of preferential policies for the exploration, development, and sale of CBM by the government is essential to promote the development of the CBM industry. The development of CBM has the characteristics of high investment, difficult production, low single-well production rate, and a long investment recovery period. Compared to conventional natural gas, the CBM industry in China lacks competitiveness. In 2016, the notice on the subsidy standards for the development and utilization of CBM (CMM) during the 13th Five-Year Plan increased the state subsidies for CBM from CNY 0.2/cbm (USD 0.029/cbm) to CNY 0.3/cbm (USD 0.044/cbm). Although the state has promulgated some preferential policies to encourage the development and utilization of CBM, economic policies and regulations are still not systematic. China's current CBM development and utilization tax reduction and exemption policies are similar to those designed for conventional gas and mainly focus on the large-scale production of CBM, lacking preferential and appropriate incentive policies. The United States has imposed a tax reduction policy on unconventional natural gas, including CBM, for more than 20 years, and the maximum deduction amount has reached 62% of the well-inlet price. Additionally, with the sluggish global economic growth, the slow domestic energy investment and less consumer demand, and the continuing decrease in the oil price, the demand for conventional energy, such as coal, electricity, oil, and gas, has dropped drastically, and the price has decreased dramatically.

In particular, the current substantial reduction in the price of natural gas has further weakened and submerged the effect of tax reduction and financial subsidies on the CBM industry. Moreover, the support of policy-related financial subsidies at the national level is relatively low. More importantly, some local governments have issued corresponding policies to specify CBM consumers, limit the gas price and repatriate the value-added tax (VAT) for the retained CBM, which has greatly reduced the policy
support to CBM. Although the Chinese government pays great attention to the development of CBM, the economic support policies are still insufficient for various reasons. For example, the return of VAT to the local area usually cannot be implemented. Therefore, the current support policies still cannot fully stimulate the development of the industry. Most of the CBM producers are operating with a deficit, poor self-development ability, and decreasing investment enthusiasm.

3.5 Poor investment conditions

China’s CBM industry is still at a low level of development. At this stage, companies do introduce some foreign investment, new techniques, and advanced experiences, and local producers try to learn from these advanced techniques and engage in modification to promote CBM development in China. However, there are too many procedures for the approval of external cooperation to develop CBM in China, and these procedures usually last a long time, which affects the enthusiasm of foreign companies for investing China’s CBM industry to some extent. The entry barriers to the development of CBM are too low, and the exit mechanism is not perfect. The existing foreign partners are not strong in economic and technical aspects, and the cooperation is not effective.81,82

Although in recent years, the state has paid great attention to CBM industry development and has continuously increased investment in this area, in general, the investment in exploration and development is far less than the demand to develop the CBM industry. Figure 4 indicates that not only private and foreign companies but also state CBM companies reduced their investment in CBM. As a result, the number of newly drilled CBM wells has drastically decreased since 2013. Due to institutional constraints, a large amount of social investment flows to the middle and downstream industries with flexible characteristics. However, the upstream industry is mainly supported by the CBM companies managed by the government, which results in insufficient investments.83

3.6 Ill-defined laws, regulations, and macroeconomic regulation

China’s CBM industry involves many departments, such as coal, land, taxation, electricity, and environmental production departments.84 The initial stage of developing CBM requires guidance, regulation, support, and supervision from the government. As shown in Table 2, China’s CBM industry lacks relevant laws (only coal law), regulations and macro-control, and there are no marketing systems, evaluations of developers’ qualifications, safety utilization management standards and quality standards, or regulations to protect the gas resources and industry. Many works cannot be carried out normally and orderly because of the lack of systematic management. At the early stage of the 12th Five-Year Plan, under the guidance of the national policy, the construction of CBM wells increased significantly.85 However, due to the incomplete organization and management, some explorations and developments have proceeded in a disorderly manner. Some CBM companies excessively utilize low-cost measures during the drilling and fracturing of CBM wells. Construction teams of poor quality or with unqualified equipment can also be found. These seriously affected the quality of the CBM wells, resulting in damage to the CBM wells and the development of CBM blocks.

3.7 Customer market needs to be developed

In the commercialization of the CBM industry, there must be support from pipeline and transportation systems with complete design, reasonable structure, and smooth access, such as pressurized treatment, ground-level transportation, and pipeline construction.112 At present, China’s natural gas pipeline network is not extensive enough. Especially within the scope of coal fields, there are no suitable natural gas pipelines. There is a serious lack of facilities designed for consumers and there is a lack of unified planning and coordination of pipeline network construction. The weak infrastructure of the CBM transportation network restricts the effective connection between CBM resources and the consumer market, making it difficult for the downstream customer market to develop. As a result, CBM extracted from underground coal mines is discharged inefficently, and CBM produced on the ground cannot be connected to the market, thus limiting the development of the CBM field.

The United States has been able to form a new CBM industry in a short period of ten years. An important reason is that it has a complete natural gas network and a sound supporting infrastructure, which enable effective connections.
between upstream production and downstream utilization, reducing initial costs, shortening the cycle of investment recovery, and forming a comprehensive system.113-117 The main storage method for CBM produced in China involves the use of a ground storage tower with a small storage volume, which severely restricts the development of CBM and the related downstream customer market. Additionally, the process of CBM utilization is limited by technical or economic factors, such as the lack of standards for the transportation and utilization of low-concentration CBM, and a large amount of low-concentration CBM can only be diluted and wasted. The low price of using CBM to generate electric power yields a low profit to power generation companies and limits the use of CBM.118 Summarizing the data on the development and utilization of CBM in the past five years, as shown in Table 3, indicates that the utilization rate is below 50%, and

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**Table 2** Current laws and regulations on coal and CBM industry in China

| Institutes      | Year | Laws/Regulations/Normative documents                                                                 | References |
|-----------------|------|-------------------------------------------------------------------------------------------------------|------------|
| PRC             | 1994 | Implementing Regulations of Mineral Resources Law                                                      | 86         |
| FMCI            | 1994 | Temporary Provisions on the Management of CBM Exploration and Development                              | 87         |
| NPCSC           | 1996 | Coal law                                                                                            | 88         |
| MF and SAT      | 1996 | Temporary Provisions on the Exemption of Import Tax on Imported Materials of Coalbed Methane Exploration and Development Operation Projects | 89         |
| MLRC            | 1999 | Temporary Measures for the Evaluation Management of the Exploration and Mining Right Assessment        | 90         |
| MF, SAT and GAC | 2002 | Temporary Provisions on the Exemption of Import Tax on Imported Materials of Coalbed Methane Exploration and Development Operation Projects | 91         |
| MF, SAT and GAC | 2006 | Provisions on exemption of import tax on imported materials from coalbed methane exploration and development projects | 92         |
| GOSC            | 2006 | Several Opinions to Accelerate the Use of CBM (CMM) Drainage                                         | 71         |
| NDRC            | 2006 | The 11th Five-Year Plan on CBM (Coal Mine Gas) Development and Utilization                           | 93         |
| MLRC            | 2007 | Notice on Strengthening the Comprehensive Exploration, Mining and Management of Coal and CBM Resources | 94         |
| MF and SAT      | 2007 | Notice on Accelerating the Tax Policy Related to CBM Drainage                                         | 95         |
| NDRC            | 2007 | Notice on Implementing Opinions on Power Generation Using CBM (CMM)                                  | 96         |
| MC, NDRC and MLRC | 2007 | Notice on Further Expanding the External Cooperation of Coalbed Methane Exploitation                | 97         |
| MF              | 2007 | Implementation opinions on subsidies for the development and utilization of coalbed methane (CMM)    | 98         |
| NDRC            | 2007 | Notice on CBM price management                                                                     | 99         |
| MEP             | 2008 | Coalbed methane (Coal mine gas) emission standards (Temporary)                                       | 100        |
| PRC             | 2009 | Mineral Resources Law                                                                                | 101        |
| NEAC            | 2009 | Notice on Organizing and Carrying out Large-scale Construction of Coalbed Methane Drainage and Utilization in Key Coal Mine Areas in China | 102        |
| NEAC            | 2011 | Temporary Regulations on the Management of CBM Exploration and Development                           | 103        |
| MF, SAT and GAC | 2011 | Notice on the exemption of import tax on imported materials for coalbed methane exploration and development projects during the 12th Five-Year Plan | 104        |
| NDRC            | 2013 | The 12th Five-Year Plan on CBM (Coal Mine Gas) Development and Utilization                          | 35         |
| NEAC            | 2013 | CBM Industry Policy                                                                                  | 105        |
| GOSC            | 2013 | Opinions on Further Accelerating the Drainage and Utilization of CBM (CMM)                           | 106        |
| MLRC            | 2014 | Management Measures of Mineral Resources Exploration Block Registration                             | 107        |
| MLRC            | 2014 | Management Measures of Mineral Resources Exploitation and Registration                             | 108        |
| MLRC            | 2014 | Management Measures for the Transfer of Prospecting and Mining Rights                              | 109        |
| NEAC            | 2015 | Notice on CBM Exploration and Development Action Plan                                              | 110        |
| NDRC            | 2016 | The "13th Five-Year Plan" on CBM (Coal Mine Gas) Development and Utilization                       | 13         |
| MF              | 2016 | Notice on the subsidy standards for the development and utilization of coalbed methane (gas) during the 13th Five-Year Plan | 111        |
there is a very low utilization rate of underground extraction gas. Moreover, the abandoned mine methane (AMM) is not important in China at present but any specific policy for promoting CMM use, or reducing emission, should include AMM to ensure consideration is given to the impact of the full mining cycle. China has mirrored the German approach in its Renewable Energy Law but has not included CMM as a beneficiary of the financial incentives.5

4 | MANAGEMENT SUGGESTIONS FOR CHINA’S CBM INDUSTRY

4.1 | Formulate and improve laws and regulations

The exploration and development of CBM in China started relatively late, and it is small scale and has weak market competitiveness. Comprehensive laws and regulations are required to protect it. It is recommended that the state formulate independent CBM development and utilization laws or administrative regulations to improve and standardize CBM exploration and development, promote unified CBM exploration and development national standards and standardize the exploration and development order. The large CBM fields must be integrated and developed in accordance with uniform standards and specifications, promoting the sustained, healthy and rapid development of CBM.

The lag in the development of external cooperation blocks and the inaction of foreign operators is the largest constraint to the development of China’s CBM industry. The mining rights cooperated with foreign collaborators account for over half of the total rights, and they cover most of the favorable CBM reservoirs below 800 m.119,120 In the initial stage of cooperation with foreign investors, the threshold for foreign partners to enter China’s market is too low, with insufficient contracts and required workloads, and there are no restrictions on the contract. GOSC (2013) stipulated that a contract should be terminated if a project’s exploration and development activities violate the contract. However, the state does not provide specific and executable regulations. It is recommended that relevant departments urgently amend the CBM cooperation regulations, improve the termination regulations of the contract, and provide management to make it clear that no exploration will be extended to the blocks with low investment or to immediately terminate contracts to release the high-quality CBM resources. At the same time, the procedures to approve the overall plan for the exploration and development of CBM cooperative blocks should be simplified as much as possible, and the time of examination and approval should be shortened.121 The apparent need for costly and delaying case-by-case litigation to establish ownership where conflicts are identified must be avoided by China in establishing property law relating to CBM and CMM ownership, and rights to extract and use the gas.5 An effective regulatory system should be devised for managing the interaction between CBM and coal mining interests. Both Australia and the United Kingdom have established robust schemes which could be adapted for China. For example, Australia has policies aimed at reducing GHG emissions from coal mines which have automatically result in improvements in safety and greater use of CMM for energy purposes provided international safety standards are a prerequisite for compliance.

4.2 | Further increase in the standard of financial subsidies

Since the 11th Five-Year Plan, the majority of the CBM enterprises in China have actively participated in investment in CBM according to the national plan, and have been provided great price subsidies. Within the company, the subsidies have reached 50% of the ex-factory price of CBM.122 However, this policy may not be sustainable for a long period. If the international crude oil price continues to be low and below $60/barrel during the 13th Five-Year Plan, according to the current pricing formula for natural gas stations, the ex-factory price for CBM can be reduced to below CNY 1.25/cbm, which will cause crackdowns for the CBM industry,123 and the production target of the
13th Five-Year Plan may not be completed. As shown in Figure 5, the tax subsidy policy played a key role in the rapid development of the CBM industry before 2002. After 2008, because of the low natural gas price, the remaining recoverable reserves and net gas production decreased significantly. It is suggested that the government should distinguish the time and quantity to put in different regions and adopt certain standards to improve the subsidies to CBM according to its proportion in the market. At the same time, CBM enterprises should be exempted from income tax, and the industry should be encouraged to accelerate the use of CBM resources that are deeper than 800 m. According to the effective recovery of the ex-factory price of CBM, the national-level financing can quickly and reasonably reduce the level of subsidy, which can not only guarantee the minimum level of investment returns of mining enterprises but also reduce the pressure on the central government.

In some instances, within the United States, royalties for the use of CMM are to be paid to the owner of the gas estate. Generally, royalties of 12.5% are owed to the federal government for all mineral leases (including CMM) from federal lands. Royalties for privately owned gas estates are negotiated on a case-by-case basis. Through the North American Free Trade Agreement (NAFTA), enacted in 1994, the United States has removed all gas tariffs for gas exports/imports to or from Mexico and Canada. Meanwhile, the production tax credit was performed in the United States, which provided a dollar-for-dollar offset to CBM generators for taxes payable under the general income tax regime.

4.3 Intensify the CBM technology research and development (R&D)

Technological innovation and progress in CBM development are fundamental for the CBM industry. During the 11th Five-Year Plan and 12th Five-Year Plan, billions of yuan in funding were provided by the state to support the national science and technology major project “Development of Large Oil, Gas and CBM fields.” Through the development of key technologies and demonstrative production blocks, the project outcomes provide strong support for the successful start of the domestic CBM industry. However, for the early development of the CBM industry, the investment in scientific research, which accounts for only 10% of the total funding, is still insufficient. It is recommended to continuously increase the investment in CBM R&D by the national government and to develop innovative technologies considering the geological variations in different regions. Moreover, continued efforts should be made to develop economically applicable drilling and completion techniques, to effectively improve the gas production of single wells. More efficient modern equivalents are needed. Efficient and safe drilling requires attention not only to the drilling machine but also to the drill bits, rods, water and hydraulic power supply, and safety control systems. Importing advanced foreign instruments is a good measure. However, there is an inherent limitation on technology transfer in that the foreign original equipment manufacturers are reluctant to risk loss of intellectual property rights, and the introduced technology will not necessarily be suited to the geological conditions in many of China’s coalfields. Therefore, increasing the development of domestic technology and technology transfer are the key to solve the problem.

4.4 Encourage the venture investment in CBM exploration and development

The exploration at the early stage and the usage at the following stage both require great financial investment. The exploration and development of CBM have the characteristics of long investment and high risks to obtain benefits. The CBM producers in China are mainly oil and gas companies or coal mining companies. Oil and gas companies have economic strength in the exploration and development of CBM, but they often regard the CBM industry as a supplementary industry. They normally pay attention to short-term benefits and engage in little investment. Coal mining companies mainly rely on coal gas extraction. They start from the safe production of coal, and the production mainly depends on the safety of the coal mine and is affected by market fluctuations. Once the coal price declines, the exploration and development funds normally decrease. It is recommended that the state increase the investment in the risk exploration of CBM,
establish special funds for the exploration and development of CBM, make efforts to ensure that the CBM industry can stay on the track of rapid development and establish incentives for the exploration and development of CBM. Awards should be given to enterprises that have made large contributions to CBM exploration, development, and utilization to promote their enthusiasm and initiative, stimulate their investment and broaden their financing chains. Some efforts should also be made to encourage venture investment and attract various investors to actively benefit CBM exploration and development. The Australian government has opted for under the Commonwealth Greenhouse Gas Abatement Programme (GGAP) to encourage the mitigation of emissions from CMM from mines and the generation of electricity from this fuel. With US$304 million allocated to the program, GGAP tends to support large-scale activities by way of grant support (up to 50% of the investment cost) through a competitive process.\textsuperscript{5}\n
Under the help of GGAP, many CBM/CMM projects have received funding, and the proved reserves and output of CBM/CMM have achieved large-scale growth in recent years.

4.5 Strengthen the public welfare services on CBM exploration and development

During the 12th Five-Year Plan, the new proven geological reserves were confirmed to be approximately 350.4 bcm, which was only 35% of the planned target of 1000 bcm.\textsuperscript{35}\n
Among them, there were almost no new proven reserves in 2015 (just 2.63 bcm; see Figure 2), and evaluations of the strategic constituency in other basins were almost stagnant. At the end of 2018, the proven rate of CBM resources lower than 2000 m was only 2.4% in China.\textsuperscript{125} The exploration and evaluation of deep CBM and strategic constituencies lay behind as well, and the capacity of the CBM industry was seriously deficient.\textsuperscript{126} Given the high cost and difficulty of gas production, all investment projects are ranked according to their investment efficiency and risk level, which makes it difficult to establish exploration projects for deep CBM. It is expected that during the 13th Five-Year Plan, CBM exploration and development in China will gradually involve deep CBM resources that are lower than 1000 m, which is another area where conventional technologies are not suitable.\textsuperscript{127}\n
Taking a state-owned enterprise as an example, the implementation of the exploration, evaluation and testing of deep CBM below 1000 m takes at least 5 years and is calculated based on 50% own investment and loans, including investment of 4.5% provided by the State-owned Assets Supervision and Administration Commission of the State Council (SASAC), and the investment cost of the project is over 20% of the construction investment, which leads to many difficulties for an enterprise considering deep CBM exploration.\textsuperscript{124}\n
The following recommendations are presented. (a) The government should directly provide support for the investment in deep CBM and strategic exploration projects by providing over 20% of the required investment from the state's budget to reasonably reduce the burden of the enterprise. The Australian government can provide support to CBM/CMM projects by way of a 50% grant at federal level, State incentives such as the Gas Electricity Certificates program in the State of Queensland and New South Wales Greenhouse Abatement Credits in the State of New South Wales can provide additional market support to CBM/CMM schemes by way of a market obligation placed on energy suppliers.\textsuperscript{5} Meanwhile, the state should further strengthen the establishment, investment, and demonstration of public welfare projects to strengthen the fundamental theory of exploration, development, and evaluation of CBM resources, such as low-rank coal, structural coal, soft coal, and deep coal seams. (b) The state should also promote the application of CBM exploration and the development of advanced techniques, to improve multiusage techniques, such as surface drainage technology, depressurization drainage at coal mines, and the reuse of wells in goaf areas to provide preliminary guidance to decrease the difficulties of the CBM industry. (c) The state should further improve the income distribution mechanism for resource development, precisely support poverty areas by developing natural resources in an environmentally friendly way, effectively improve the level of public service of geological surveys and the level of infrastructure sharing, promote the transformation and development of resource-based cities, improve the economy in poverty areas and develop cooperation between the government and the local enterprise in the CBM industry. (d) Moreover, relevant incentive policies should also be implemented in China to improve CBM/CMM utilization. In Germany, electricity generated from AMM/CMM projects benefit from a predetermined power offtake price of US$96.9 Mega Watt (s) Per Hour (MWh) for the first 0.5 MW and US$84.0/MWh thereafter, given to renewable technologies, which is significantly higher than wholesale electricity prices (US$36.6/MWh) and consequently provides a strong incentive to CMM developers to exploit the full potential of this energy source.\textsuperscript{5}\n
4.6 Reform and optimize the CBM tenure management

The state should standardize the order of the exploration and development of coal and CBM. When new prospecting rights are established, coal and CBM must be comprehensively inspected, evaluated, and identified as reserves to ensure that both coal and CBM rights do not have new large-scale overlapping areas.\textsuperscript{70} The state must resolutely implement the policy of “gas production first, followed by coal mining” for blocks containing CBM higher than the national standard when there are suitable ground development conditions, giving priority to CBM ground extraction to achieve the coordinated exploration and development of CBM and coal. The state should encourage coal companies and CBM
enterprises to cooperate and negotiate the overlap of existing mining rights to achieve a win-win situation. For the CBM resource enriched areas that have not yet been developed, priority should be given to the exploration, development, and utilization of CBM. Coal mining rights should not be duplicated, or both coal and CBM rights should be set at the same time to benefit both. As in Australia and the United Kingdom, the coal authority will require the developer of a CBM project to provide a comprehensive risk assessment covering the potential impacts of the proposed scheme, including the interaction with mine operators and surface safety considerations. The coal mining rights holders should cooperate in the exploitation of CBM, and the CBM producers should take the operation of coal into consideration during gas production. Coal mining companies should provide technology and assistance to cooperate with CBM enterprises’ production operations.

Taking the exploration and mining entrustment pilot projects of CBM as a breakthrough, the reform of the exploration and mining system for CBM resources should be steadily pushed forward through the following measures: (a) Establishing a competitive CBM exploration right transfer system that is suitable for exploration of CBM, in which the decisive role of marketing can be fully used. (b) Strictly controlling the CBM prospecting right extension registration, raising the exploration right holding cost and the minimum exploration investment standard, improving the exit or withdrawal mechanism, and promoting the orderly operation of the project. (c) Improving the public and sharing mechanism of oil and gas geological data, establishing a dynamic supervision and information platform for oil and gas resources, implementing an annual information disclosure system for the exploration and exploitation of CBM, and investigating the establishment of a new system for the management of CBM resources at the national and local levels of registration and supervision. (d) Continuing regulatory reforms and further liberalizing energy markets to achieve more rapid development of CBM and CMM resources.

5 | CONCLUSIONS

The development trend and scale of the CBM market in China are closely related to the national development strategy and the economic conditions. The international market of natural gas dominates the development trend of CBM in China. The large shortage in China's natural gas at the current stage has stimulated the development of China's CBM industry to some extent. As an important part of unconventional gas, CBM will emerge in the natural gas market and produce enormous potential for energy resources. However, the development of China’s CBM industry is still in its infancy, and there are still many problems that need to be solved.

- Price has always been the most sensitive and controlling factor in the development of the CBM market. The international CBM price plays an important role in the CBM market. China’s CBM market pricing mechanism is still not perfect. It is necessary to increase technical and financial support to ease the relationship between pricing and costs, market supply and demand.
- CBM exploration in China has currently fallen into a serious stagnation. The direct reason is insufficient investment. How to find a scientifically based solution that effectively addresses investment enthusiasm and market development is important to increase and accelerate the development of the CBM industry in China.
- The contradiction between CBM development and coal mining is becoming increasingly serious, and CBM overlaps with coal mining rights. Meanwhile, the fragmentation of coal mining rights is incompatible with the regional requirements for exploration and development of CBM. The policy of “producing gas first, producing coal second” must be implemented. The phenomenon of “no exploring CBM or exploring CBM without producing” must be eliminated.
- The storage of CBM and its production process are very complicated and require the development of advanced techniques. The lack of mature CBM geology theory, independent intellectual property rights that are suitable for China’s geological conditions, and technologies supporting CBM exploration and development is one of the major contradictions that restrict the development of China’s CBM industry.
- The imperfection of the CBM industrial chain has seriously affected the development of the CBM industry in China. The main problems in the exploitation and utilization of CBM resources in China are the low extraction and utilization rates. A complete pipeline network will greatly promote the progress of the CBM industry, and the construction of infrastructure is the top priority for the development of the CBM industry in China.
- CBM subsidies and support policy have low incentives, and the implementation is not in place. The subsidy standards are low, lack flexibility and reveal regional differences. The level of subsidies after the increase is still insufficient. The CBM financial subsidy standard should be increased as in real-time, as appropriate for each region and adopted based on a certain market price ratio.

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