View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Elsevier - Publisher Connector

HOSTED BY

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Natural Gas Industry B 1 (2014) 1−13

www.elsevier.com/locate/ngib

Research article

Prospects of and challenges to natural gas industry development in China

Jia Chengzao [a,b,*], Zhang Yongfeng [b], Zhao Xia [b]

[a] *PetroChina Company Limited, Beijing 100007, China*

[b] *Research Institute of Petroleum Exploration & Development, PetroChina, Beijing 100083, China*

Received 9 January 2014; accepted 25 February 2014

Available online 15 October 2014

Abstract

An unprecedented breakthrough has been made over the past decades in natural gas industry, which helps improve energy mix and promote the low-carbon economy in China. With such abundant hydrocarbon resources, China owns two intensive oil and gas producing blocks in the Ordos Basin and Xinjiang province and two other concentrated gas producing blocks in Sichuan and Western South Sea. In addition, arterial gas lines have been connected as a gas grid all over China and natural gas market has become more and more mature and expanded. Thus, a natural gas industry system has come into being. However, with natural gas unevenly scattering all across China, the remnant resources mainly are distributed in the stratigraphic strata, deep strata in superimposed basins or in mature exploration zones, foreland basin thrust belts, marine gas fields, and so on. In reality, the future gas exploration should focus on such domains as the weathered crust karst reservoirs or carbonate and stratigraphic traps, deep clastic gas layers, and unconventional oil and gas plays. Achievements have been made in marine shale gas exploration, CBM gas steady development, and other unconventional natural gas resources. From the perspective of exploration potential, more giant oil and gas fields will be possibly discovered in deep strata or deep sea water, and stratigraphic hydrocarbon reservoirs and tight oil and gas reservoirs will also be the exploration focus. With the increase of exploration depth and degree, the overall oil and gas exploration cost will be significantly rising in general. New discoveries or reserves increase in natural gas exploration will highly depend upon research theory and technology progress, and such development technologies as 3D seismic survey, horizontal drilling and fracturing treatment will be more highlighted. Through enhancing the cost in natural gas exploration and development and strengthening the research of core technologies, natural gas industry will keep the trend of rapid growth in near future in China.

© 2014 Sichuan Petroleum Administration. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).

Keywords: China; Natural gas; Resource distribution; Residual resources; Deep sea water; Tight oil and gas reservoir

With the rapid development of world economy and continuously increasing population and energy consumption, the emission of greenhouse gas and a variety of harmful substances has surged sharply, leading to a deteriorated living environment for human beings. Faced with these challenges, clean and high-calorific-value natural gas energy has drawn more and more attention, and developing the natural gas industry has become the best option for the world to improve the environment and promote sustainable development of economy.

1. The status quo and development trend of global natural gas industry

1.1. The status quo of global natural gas industry development

Currently, oil and natural gas are among the most important primary energy sources and enjoy an important standing in the structure of global energy consumption. According to statistics, the global primary energy consumption was 124.8×10^8 t oil equivalent in 2012, an increase of 1.8% compared with that in 2011. The structure of energy consumption reveals that, the fossil energy sources including oil, natural gas and coal are still the most dominant in the world. Oil consumption accounts

* Corresponding author. PetroChina Company Limited, Beijing 100007, China. Tel.: +86 10 84886011; fax: +86 10 84886002.

E-mail address: jiacz@petrochina.com.cn (Jia CZ).

Peer review under responsibility of Sichuan Petroleum Administration.

http://dx.doi.org/10.1016/j.ngib.2014.10.001

2352-8540/© 2014 Sichuan Petroleum Administration. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).

for 33% of global primary energy consumption, natural gas 24%, and coal 30%. The data is sourced from *BP Statistical Review of World Energy 2013*.

In 2012, the total primary energy consumption in China was 27.35×10^8 t oil equivalent, with coal, oil and natural gas being the main components. According to statistics, coal consumption was 18.73×10^8 t oil equivalent, accounting for about 68%; the oil consumption was 4.84×10^8 t, accounting for 18%; and natural gas consumption was 1438×10^8 m^3 (about 1.30×10^8 t oil equivalent), accounting for 4.8%. The total consumption of these three kinds of fossil fuels accounts for approximately 91% of the total consumption of primary energy sources in China. But as viewed from their respective consumption, coal is still the main component in energy consumed in China, while the proportion of natural gas in primary energy consumed in China is not high, with a big gap from the average proportion (24%) of the world natural gas consumption.

The global natural gas output is basically equal to the consumption. In 2012, the global natural gas output was 3.36×10^{12} m^3 and consumption was 3.31×10^{12} m^3. At present, natural gas output is quite uneven throughout the world. In 2012, the total gas output of top 10 countries in the world, including the United States, Russia, Iran, Qatar, Canada, Norway, China, Saudi Arabia, Algeria and Indonesia, reached 2.23×10^{12} m^3, accounting for about 66.4% of the global total. China reported a gas output of 1072×10^8 m^3 in 2012, ranking the 7th in the world.

There is a resource basis for further development of global natural gas industry. According to an appraisal by the United States Geological Survey (USGS) on conventional oil and/gas resources of the world, the global remaining technically-recoverable resources of conventional oil (including natural gas liquid) are 2550×10^8 t, and the global remaining technically-recoverable resources of conventional natural gas are 462×10^{12} m^3. According to the definition given by USGS, the remaining technically-recoverable resources include remaining recoverable reserves, to-be-discovered technically-recoverable resources to be identified, and reserve increment growth.

The world is abundant with unconventional gas resources, and in the future the exploration and development potential will be huge. According to the appraisal by USGS, the global remaining technically-recoverable resources of unconventional gas (coalbed gas, tight gas and shale gas) are 328×10^{12} m^3 (Fig. 1), and those in the Asia—Pacific region account for 39.5%.

Energy demand has become the focus of attention all over the world. In recent years, a number of institutions and organizations have been carrying out energy development trend forecast, and the most representative forecast was made by International Energy Agency (IEA). According to the forecast made by IEA, as impacted by the active control on energy demand and the strict energy policies enforced in various countries, the total demand for primary energy throughout the world will reach up to 172×10^8 t oil equivalent by 2035, with an annual growth rate of 1.2%. Fossil energy sources (oil, natural gas and coal) will remain dominant and account for about 75% in total energy consumption; renewable energy will gradually catch up and a proportion of about 25% in total energy consumption is anticipated. According to the prediction results by IEA, the global natural gas output will be ramped up to 3.94×10^{12} m^3 in 2020 and 4.96×10^{12} m^3 in 2035.

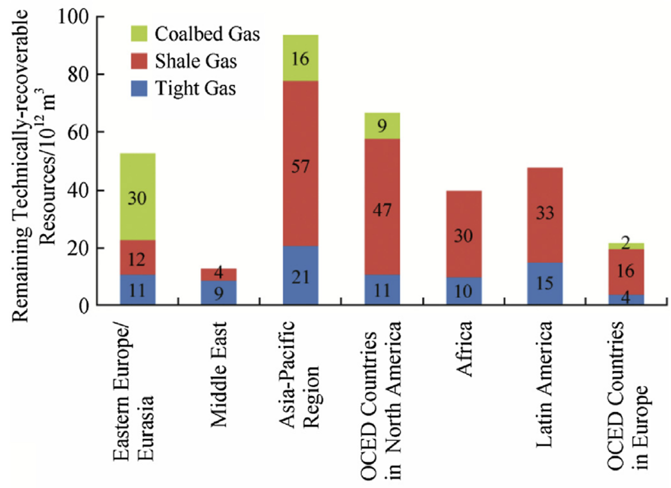

Fig. 1. Global distribution of remaining technically-recoverable unconventional natural gas resources. Notes: The data is sourced from USGS (2012); OECD refers to the Organization for Economic Co-operation and Development.

1.2. The development trend of global natural gas industry

An analysis on global gas market and transportation situations of natural gas throughout the world reveals that the following five trends will appear in natural gas industry development.

1.2.1. The global natural gas consumption will continue to grow rapidly and continuously, with the Asia—Pacific region enjoying the highest growth rate

According to the statistics of BP, in 2012, natural gas consumption of OECD (Organization for Economic Co-operation and Development) countries was 1.59×10^{12} m^3, an increase of 2.5% compared with that in 2011, constituting 47.92% of the global total. Natural gas consumption in non-OECD countries was 1.73×10^{12} m^3, an increase of 2.0% compared with that in 2011, constituting 52.08% in the global total. With respect to natural gas consumption in different regions, except for Europe and Eurasia with consumption decrease, the consumption in all other regions has been on the rise steadily. In particular, the Asia—Pacific region saw a rapid rise of the proportion of natural gas consumption in the global total, from 12.5% in 2001 to 18.86% in 2012, recording the fastest growth rate in the world (Table 1).

Table 1
Natural gas consumption in different regions in the world during 2002—2012.

Region	2001	2006	2007	2008	2009	2010	2011	2012	Proportion in global consumption in 2012	Growth rate in 2012 compared in 2011 (10^{12} m^3)
North America	0.761	0.778	0.814	0.821	0.816	0.850	0.868	0.907	27.35%	4.49%
Central and South America	0.100	0.136	0.136	0.141	0.137	0.152	0.156	0.165	4.98%	5.77%
Europe and Eurasia	1.014	1.120	1.126	1.136	1.049	1.130	1.106	1.083	32.68%	−2.07%
Middle East	0.207	0.291	0.303	0.332	0.345	0.377	0.395	0.412	12.42%	4.30%
Africa	0.066	0.089	0.095	0.101	0.100	0.108	0.114	0.123	3.71%	7.89%
Asia—Pacific Region	0.308	0.424	0.457	0.480	0.497	0.560	0.594	0.625	18.86%	5.22%
Global Total	2.455	2.839	2.932	3.011	2.944	3.176	3.232	3.314	100.00%	2.54%
OECD Countries	1.341	1.433	1.478	1.505	1.463	1.556	1.544	1.588	47.92%	2.85%
Non-OECD Countries	1.114	1.406	1.454	1.506	1.481	1.620	1.688	1.726	52.08%	2.25%

Note: The data is sourced from BP Statistical Review of World Energy 2013; please note that, there are nuances between the global total and the sum of different regions, which is caused by rounding off of last digit following the decimal point.

1.2.2. Global natural gas consumption will keep growing before 2035 and the consumption center will move to the eastern hemisphere

Global natural gas demand will keep growing in the future, at different rates in different regions. The growth rate in OECD countries will be relatively slow, and the increment will mainly come from emerging economies represented by China and India. The Asia—Pacific region and the Middle East will be the regions with the highest growth rate of natural gas consumption, and the proportion of these regions in global natural gas consumption will increase gradually. As a result, the trend that the consumption center will gradually move to the eastern hemisphere will become increasingly obvious. The growth of natural gas demand in mature markets such as North America and Europe will be relatively slow, but the proportion of these regions in global natural gas consumption will still be the highest (Fig. 2).

1.2.3. Global natural gas trading volume has grown rapidly and is expected to constitute more than 1/3 of total consumption by 2035

At present, the global natural gas market is still featured with that most of the resources utilized are inner-regional, while trans-regional resources serve as the subsidiary. In 2012, the global gas trading volume was 1.033 4 $\times$ 10^{12} m^3, accounting for 31% (close to 1/3) in global gas consumption. The trading volume of piped gas was 7055 $\times$ 10^8 m^3, accounting for 68.3% of total gas trading volume; and LNG was 3279 $\times$ 10^8 m^3, accounting for 31.7% (Fig. 3).

According to a forecast by IEA, the global gas trading volume will reach up to approximately 1.2 $\times$ 10^{12} m^3 by 2035, an increase of about 80% compared with that in 2010 (6750 $\times$ 10^8 m^3), while the growth rate of gas output during the same period will be slower (50%). In 2011, the trading volume of trans-regional piped gas accounted for 58% of total gas trading volume, and if the short-distance piped gas trading was taken into account, the proportion would rise up to 68%. With the construction of pipelines from Europe to China and the pipelines from Caspian Sea to Europe and India, it is anticipated that by 2035 the trading volume of piped gas will account for 50% of trans-regional gas trading volume in the world. Meanwhile, LNG trading volume will exceed 5750 $\times$ 10^8 m^3 by 2035, with the proportion in total gas trading volume rising to 50% from 42% in 2011.

In the future, China will be the country enjoying the rapidest growth of natural gas trading volume in the world. It is

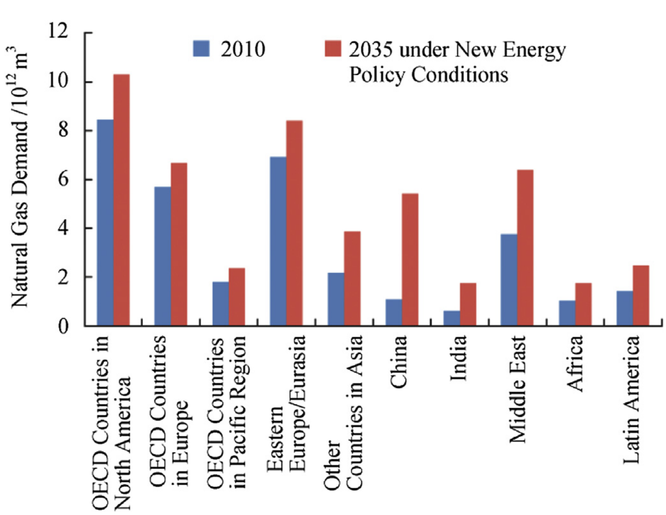

Fig. 2. Natural gas demand in various regions through the world in 2035. Note: The data is sourced from World Energy Outlook 2012 issued by IEA.

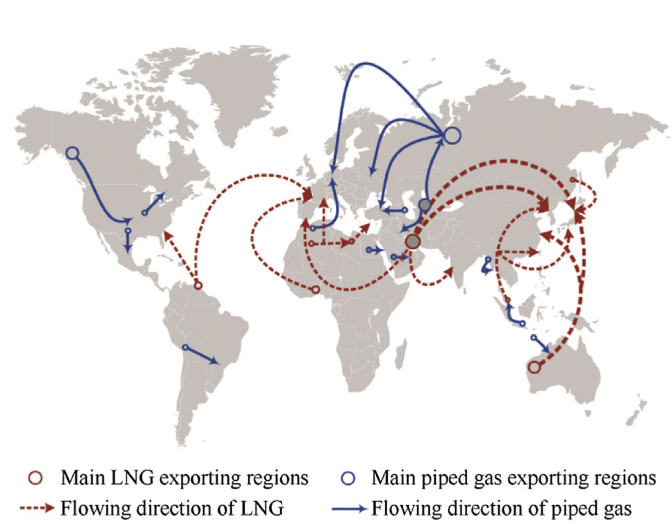

Fig. 3. Flowing direction of world natural gas in 2012.

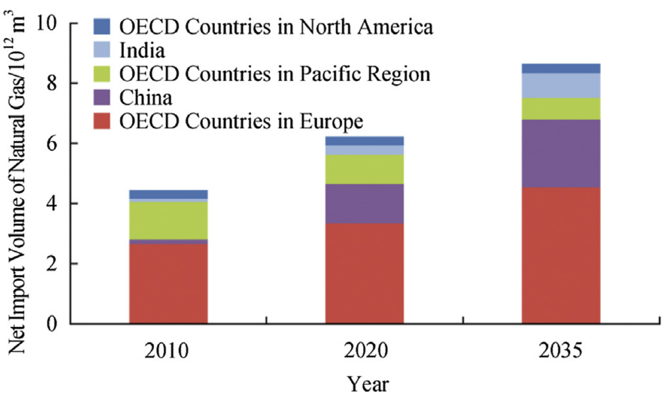

Fig. 4. Net import volume of natural gas in different regions in 2035. Note: The data is sourced from World Energy Outlook 2012 issued by IEA.

predicted that the natural gas trading volume in China will increase from 150 × 10^8 m^3 in 2010 to 2260 × 10^8 m^3 in 2035, China will become the largest LNG importer second only to Europe by 2025 and the largest LNG importer in the world by 2035, and its import volume will take up 1/3 of global LNG supply (Fig. 4).

1.2.4. Global natural gas price will show regional features

Different from crude oil market, natural gas market has regional features. With respect to gas consumption markets, there are three major consumption markets in the world, namely North America, Europe and Asia–Pacific Region. With respect to the gas market price however, no global benchmark price has been formed, and there are six main price forms, among which three pricing mechanisms including gas-on-gas competition, oil price index and government regulation account for about 90% in all gas pricing methods in the world (as per consumption price). With respect to gas price level, at present, the price in North America is the lowest, Eastern Asia the highest, and Europe the middle. The proportion of annual average gas price in America, Europe and Asia rose from 1.0 : 2.3 : 3.8 in 2011 to 1.0 : 3.3 : 6.0 in 2012. In the United States, the average gas price in HenryHubannual is US$2.82/MMBtu (Btu, british thermal unit, 1 Btu ≈ 1055 J, the same below), a year-on-year decrease of 29.7% and the lowest price since the beginning of 21st century. In the UK, the NBP price basically remains at US$8–10/MMBtu, and the annual average price is US$9.43/MMBtu, a year-on-year increase of 4.4%. In Asia–Pacific region, the price of imported LNG in Japan is still at the global highest level, and the annual average price is US$16.9/MMBtu, a year-on-year increase of 15.8%.

1.2.5. Global natural gas pipeline construction will continue to maintain a rapid development

With the rapid growth of global natural gas demand, the natural gas pipeline sector has enjoyed a robust development. By the end of 2013, there were 64 in-service long-distance oil and gas pipelines [put into operation since 2005] with the length exceeding 400 miles (about 643.7 km) throughout the world, with the total length reaching up to about 8.1 × 10^4 km; among them, there were 34 gas pipelines, with a total length of 4.18 × 10^4 km accounting for 51.6% of the total length of oil and gas pipelines throughout the world, and most of them were in the Asia–Pacific region and the Central Asian Region of Russia [1].

2. The status quo and development trend of natural gas industry in China

2.1. The status quo of natural gas industry in China

China has found 505 sedimentary basins of different types. Till now the government has approved 1746 leases with the total area of 435.4 × 10^4 km^2. According to the results of new-round evaluation on the nationwide oil and gas resources carried out in 2005, the recoverable resources of conventional oil and gas in China are 255 × 10^8 t for oil and 27 × 10^{12} m^3 for natural gas. China is also abundant with unconventional oil and gas resources. Results of preliminary evaluation revealed that unconventional oil and gas resources are basically equal to conventional oil and gas resources in China. As exploration is intensified, there is still room for the increase of unconventional oil and gas resources in China.

After more than half a century of arduous exploration, China has discovered 900 oil and gas fields, including 660 oil fields and 240 gas fields; proven OIP is 324 × 10^8 t and proven GIP (gas in place) 8.3 × 10^{12} m^3; remaining recoverable oil reserves are 31.6 × 10^8 t and remaining recoverable gas reserves are 3.86 × 10^{12} m^3. In 2012, China produced 2.08 × 10^8 t crude oil, ranking the 4th in the world; and 1072 × 10^8 m^3 natural gas, ranking the 7th in the world.

With respect to the development of natural gas industry in China, although the utilization of natural gas enjoys a long history in China, natural gas industry has developed just along with the development of oil industry and is relatively late in development. Since the 8th Five-year Plan period, owing to the breakthroughs made successively in basic geological research on natural gas in China, natural gas industry has entered into a rapid development stage. In particular, in recent 10 years, natural gas industry in China has developed much faster. With respect to the annual reserve growth, the annual average proven GIP was 861 × 10^8 m^3 during the 9th Five-year Plan period and grew to 4305 × 10^8 m^3 during the 10th Five-year Plan period and to 5358 × 10^8 m^3 during the 11th Five-year Plan period, 6.2 times of that during the 9th Five-year Plan period.

With respect to change in natural gas output, the recent 10 years are also the period of rapid growth for natural gas output in China, during which the annual average growth rate is 11.6%, and the ranking relating to natural gas output has also been on the rise. In 2000, China's natural gas output was 272 × 10^8 m^3, ranking the 19th in the world; but the output was 1072 × 10^8 m^3 in 2012, rising up to the 7th in the world.

At present, two major oil regions, two major oil and gas regions and two major gas regions have been formed preliminarily in China. The two major oil and gas regions in Ordos and Xinjiang produce 516 × 10^8 m^3 natural gas per year, accounting for 48% of China's total gas output; the two major gas regions in Sichuan Basin and northern South China Sea

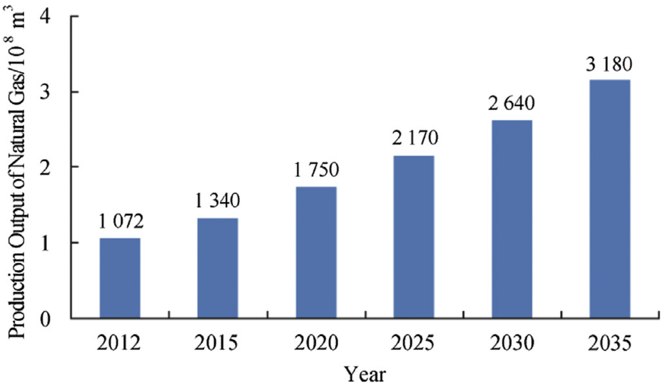

Fig. 5. Growth trend of China's natural gas output predicted by IEA.

produce 312 × 10^8 m^3 natural gas per year, accounting for 29% of China's total gas output. Obviously, these two major oil and gas regions and two major gas regions are the backbone for natural gas production in China, whose gas output takes up 77% of the total in China.

2.2. The development trend of natural gas industry in China

However, owing to the rapid development of China's national economy, people's raised living standards and the duty to protect the environment, China enjoys a rare opportunity for developing natural gas industry. With the deepening understanding of gas accumulation and the progress and development of exploration technologies, China's natural gas industry will continue to develop rapidly in a considerable long period. According to the forecast by IEA in 2012, China's natural gas output will exceed 2000 × 10^8 m^3 and reach up to 2170 × 10^8 m^3 in 2025; and will exceed 3000 × 10^8 m^3 and reach up to 3180 × 10^8 m^3 in 2035 (Fig. 5).

3. Natural gas resources and main exploration areas in China

3.1. Distribution features of natural gas resources

As is mentioned above, with 255 × 10^8 t recoverable oil resources and 27 × 10^{12} m^3 recoverable natural gas resources, China is relatively abundant with oil and gas resources.

According to the results of appraisal on remaining resources, the oil and gas resources in China are quite uneven. With respect to the distribution of remaining conventional resources, both the remaining conventional oil resources and conventional natural gas resources are mainly distributed in lithologic strata, thrust belts of foreland basins, deep layers of superimposed basins (including carbonate rocks, volcanic rocks and etc.), mature exploration areas and marine areas (Table 2), and obviously these areas are still the focus for exploration of oil and gas in China.

Judged from the potential and distribution of remaining resources, in the future, the development potential of natural gas may be greater than that of oil. Currently, the proven ratio of conventional gas resources in lithologic strata, foreland thrust belts, deep carbonate/volcanic rocks and the deep layers of mature exploration areas is still low, which means that there are the basis and potential for big increase in gas reserves and production. In addition, owing to its specific geological conditions, China is also abundant with unconventional gas resources. According to the results of relevant appraisal, unconventional gas resources in China are 188 × 10^{12}—196 × 10^{12} m^3, with technically-recoverable resources exceeding 45 × 10^{12} m^3. At present, the focus of exploration and development of natural gas in China is on conventional resources, and the development and utilization of unconventional gas resources is still in an early stage. It is expected that in the future, with the advancement of technologies in developing and utilizing unconventional natural gas, the development of natural gas industry in China will be further accelerated.

3.2. Oil and gas exploration areas in future

In recent years, aiming at the oil and gas reserves in lithological strata, foreland basins, the middle and lower portions of superimposed basins and the oil/gas-bearing belts in mature exploration areas [2—5], China has strengthened unconventional oil and gas [6—9] exploration. On the basis of geological understanding and by virtue of advanced and appropriate new technologies, great achievements have been made in oil and gas exploration. Especially, oil/gas reservoirs in deep carbonate weathering crust strata in superimposed basins as well as the deep and unconventional natural gas in foreland thrust belts have shown the great exploration potential, and

Table 2
Distribution of oil and gas resources in China.

Item		Recoverable oil resources/10^8 t			Recoverable gas resources/10^{12} m^3		
		Total resources	Proven reserves	Remaining resources	Total resources	Proven reserves	Remaining resources
Onshore	Lithologic strata	51.5	14.3	37.2	4.52	2.00	2.52
	Foreland basins	15.7	7.1	8.6	5.47	0.69	4.78
	Carbonate volcanic rocks	16.8	3.7	13.1	4.02	0.61	3.41
	Mature exploration areas	76.9	45.6	31.3	1.01	0.26	0.75
	New basins	21.9	0.1	21.8	1.76	0.00	1.76
Offshore		72.1	7.3	64.8	10.7	0.31	10.39
Total		254.9	78.1	176.8	27.48	3.87	23.61
Coalbed gas					10.90	0.05	10.85

will be the focus of exploration and development of natural gas in future.

3.2.1. Carbonate weathering crust oil/gas reservoirs

Carbonate weathering crust oil/gas reservoirs are widely developed in the Tarim Basin, the Sichuan Basin and the Ordos Basin in China [10−13]. According to the preliminary appraisal, there are 11 carbonate karst belts in these three major basins, and oil and gas resources are 116.5×10^8−132.5×10^8 t oil equivalent (Table 3), which means that the exploration potential is very huge.

3.2.1.1. Carbonate weathering crust oil/gas reservoirs in the Tabei area of the Tarim Basin. The Tabei area of Tarim basin is a large inherited paleo uplift which has developed for a long time, and the exploration area in Tabei area is about 3.5×10^4 km^2. With respect to the carbonate rock exploration in Tabei area, after the Yakela oil and gas field was discovered on the basis of the breakthrough made in Well Shashen 2 at the beginning of 1980s, some major breakthroughs were also made in carbonate rock exploration in 1990s, and the Lunnan-Tahe oil and gas field with a reserve exceeding 10×10^8 t was found [14]. In recent years, with the continuous development of geological knowledge and the constant advancement of exploration technologies, new breakthroughs and discoveries have been made in oil and gas exploration on the southern edge of Tabei area, with the range of exploration extending to the lower parts of slopes and the exploration depth exceeding 7000 m. By the end of 2012, the proven OIP (oil in place) found in the carbonate rocks in Tabei area reached 15.6×10^8 t, so Tabei area became the oil and gas field with the largest oil and gas reserves in continental carbonate sequence in China.

In the Tarim basin, there are two sets of widely-distributed middle lower Cambrian and middle upper Ordovican source rocks developed in the Palaeozoic Group. Tabei area is a long-term inherited paleo uplift adjacent to Halahatang and Lunnan-Chaohu hydrocarbon-generating depressions, so its hydrocarbon source conditions are favorable. Reef-beach complexes have widely developed in the Yingshan Formation, the Yijianfang Formation and the Lianglitage Formation of Ordovican System. As impacted by along-stratum and inner-stratum karst effect, karst fractures/caves have developed, and the weathering-crust-based and internal-layer-based karst fracture/cave type reservoirs have been formed. Various karst fractures/caves overlapped longitudinally with each other and connected horizontally. Since the distribution area is large, those fractures are relatively stable in the lateral direction. The fracture/cave type reservoir strata are distributed in a relatively centralized manner. The Shangtamu argillaceous rocks and Carboniferous argillaceous rocks are regionally distributed, which, together with the lower Ordovician karst fracture/cave type reservoir strata, constitute a favorable accumulation-covering combination. The reservoir strata show the characteristics of multiphase hydrocarbon generation, filling and accumulation [15−17]. The distribution of oil and gas is not controlled by local structures, the karst reservoir section with high lamination has the obvious features of stratigraphic type oil and gas reservoir, and its distribution scope is relatively large. Recently, PetroChina Company Limited has found the Halahatang Oilfield with a reserve exceeding 5×10^8 t through exploration in Halahatang on the southern end of the

Table 3
Statistical results of oil/gas resource potential in carbonate weathering crust strata in the favorable zones of the three major onshore basins in China.

Basin	Zone	Reservoir stratum	Area/10^4 km^2	Resources/10^8 t oil equivalent
Tarim	Yingmaili-Yaha Buried Hill Zone	Several karst reservoir strata in Yijianfang Formation and Yingshan Formation in Cambrian System, of which the thickness is 70−250 m	0.22	6.6
	Lower uplift in Manxi	Karst of Yingshang Formation	1.50	6.0−9.0
	Ordovican System in southern edge of Tabei area of Tarim basin	Three karst reservoir strata in Lianglitage Formation, YIjianfang Formation and Yingshan Formation, of which the thickness is 70−250 m	1.75	25.2
	Weathering crust of Yinshan Formation in Central Tarim	Karst reservoir stratum	0.59	13.4
	Maigaiti Slope and its circumference	Karst reservoir stratum in Yingshan Formation, and karst reservoir stratum in Yingshan Formation	0.83	14.0
	Ancient city area in Eastern Tarim	Karst reservoir stratum in Dengying Formation of Sinian System, and penecontemporaneous pore dolomite tyope reservoir stratum of Cambrian System	0.14	6.0−8.0
Sichuan	Leshan-Longnvshi paleo uplift	Lei 4 Member of Leikoupo Formation	1.10	31.0−42.0
	Weathering crust of Leikoupo Formation	Qixia Formation and Maokou Formation in Low Permian System	1.50	3.2
	Weathering crust in paleo uplift in Luzhou	Weathering crust of Mawu 1-4 Sub-members in Lower Ordovican System	0.45	2.5
Ordos	Western portion of Jingbian	Grain beach of Mawu 5-10 Sub-members in Lower Ordovican System	1.15	4.8
	Eastern portion of paleo uplift		1.28	3.8
Subtotal			10.51	116.5−132.5

uplift in Tabei area, with the exploration range extended from the upper slope of the uplift in the early stage to the lower slope of the uplift and the exploration area doubled. The current research findings indicate that, in the Yingshan Formation, Yijianfang Formation and Lianglitage Formation of the Ordovican System in Tarim Basin, the karst reservoir strata are widely distributed. A breakthrough has been made in exploration in the Ordovican karst reservoir stratum in the northern slope in Central Tarim, Manxi has also the foundation and conditions for the development of karst reservoirs, and Tabei − Manxi − Tazhong − Tadong may become a large oil and gas zone where oil and gas is distributed everywhere and is enriched in some places. If this oil/gas-bearing pattern is proved through exploration, then the exploration scale will be very large. The key technical bottleneck which will constrain the exploration and development is the prediction and depiction on fractured-vuggy reservoir strata as well as the appraisal on favorable enrichment zones.

3.2.1.2. The lower Palaeozoic in the Ordos Basin. Covering an area of 37×10^4 km^2, the Ordos Basin is abundant with oil and much more gas. The favorable Lower Palaeozoic carbonate rock type exploration area reaches about 4×10^4 km^2, with geological gas resources of 2.55×10^{12} m^3. From the end of 1980s when the Jingbian gas field was found through carbonate rock exploration in this basin to 2012, the accumulative proven GIP found in Ordovician weathering crust dolomite type reservoir strata in this basin reached 6552×10^8 m^3, which indicates a good exploration prospect for natural gas in carbonate weathering crust type reservoir strata.

As for the carbonate rocks in this basin, the weathering crust dolomite type reservoir stratum of the Majiagou Formation in the Ordovican System is taken as the main target. The coal-measure strata formed owing to the sedimentation of Carboniferous-Permian coastal plain environment have the characteristics of large thickness, wide distribution, high organic content, high thermal evolution degree and high gas-generating intensity, and the widely-distributed Upper Paleozoic Carboniferous-Permian coal-measure stratum provides rich gas source and covering conditions for the accumulation of Lower Ordovican carbonate rocks. The stable deposit of Cambrian-Ordovican System in the Lower Paleozoic period has experienced a long-term uplifting erosion and weathering effect, and from west to east, namely from Mawu-1 Submember to Mawu-10 Submember and then to Mate Point, four sections with relatively high laminarization ability are successively exposed above ground. The karst reservoir in the exposed section of stratum in Mawu-5 Submember directly contacts with the upper coal-measure stratum, constituting a good combination of upper generation and lower accumulation, and the source reservoir is of good configuration. Towards the eastern and up direction, dolomites in the Mawu Member of the Majiagou Formation are converted into micritic limestones, so an effective sealing is formed, which facilitates the formation of stratigraphical and lithological gas reservoirs. It is revealed through research that, this exposed section is large and occupies the central proportion of the whole basin, and the exposed surface is covered with the huge-thick Carboniferous-Permian high-quality source rocks, which provides favorable conditions for a wide distribution of weathering crust oil/gas reservoirs [18−20].

Since the 11th Five-year Plan period, guided by the understanding that the Ordovician weathering crust karst reservoir stratum is widely distributed [10,12,13] and bears gas, the research and appraisal on the western karst belt in the Jingbian Gas Field have been strengthened. In 2010, industrial gas flow was obtained in Well Su 51H through exploration in weathering crust dolomite-type reservoir stratum in the Mawu Member; during 2011−2012, six favorable natural gas-enriched areas were found in the Mawu-5 Sub-member in the Ordovician System, forming a new reserve of one hundred billion cubic meters; in addition, new findings have been obtained in Mawu 6-10 Submembers, and good indications have also been found in the lower combination, which means that this basin, with the overlapped carbonate weathering crusts, enjoys high exploration potential, and such strata will become the most feasible exploration area in the Ordos Basin.

3.2.2. Deep exploration areas

Most oil/gas-bearing basins in China are superimposed ones, and have two oil/gas-bearing systems in medium-shallow layers and deep layers [21,22]. According to the results of new-round appraisal on oil/gas resources, the remaining geological resources of deep oil in China are 277.1×10^8 t, and the remaining geological resources of natural gas are 26.62×10^{12} m^3. Recently, major breakthroughs have been made in areas such as Sinian-Cambrian carbonate rocks in the paleo uplift in the Sichuan Basin, clastic rocks in foreland thrust belts in the Kuqa depression in the Tarim Basin, carbonate rocks in Tabei and Tazhong areas, deep buried hills in the Bohai Bay Basin and the middle-deep layers in the Yinggehai Basin in China, suggesting resource scale and prospect are good. It is expected that with the improvement of geological understanding and the advancement of exploration technologies, the deep oil/gas resources will make important contribution to the development of oil and gas industry in China in the future.

3.2.2.1. Kelasu deep clastic rocks in Kuqa in the Tarim Basin. Covering an area of about 2.85×10^4 km^2 and having geological oil resources of 12.5×10^8 t and geological gas resources of 3.6×10^{12} m^3, the Tarim Basin Kuqa foreland basin is an important area for gas exploration and development in China. It is the main gas source for the West-to-East Gas Transmission Project. The Kelasu tectonic zone is the most important gas-bearing belt in the foreland thrust belt in Kuqa [23−25]. In 1998, with the Paleogene pre-salt stratum as the main target layer for exploration, the largest clastic rock type onshore large gas field in China, namely Kela-2 Gas Field, was found in Kelasu anticline belt, which has promoted the initiation of the West-to-East Gas Transmission Project. However, a batch of exploration wells subsequently drilled in the pre-salt middle-shallow layer failed successively. By 2008 when the high-yield gas flow was obtained in Well Keshen-2 drilled on the basis of pre-salt deep structures, the exploration potential of deep gas had then been revealed.

The Kelasu tectonic zone is located at the Triassic and Jurassic hydrocarbon-generating center in the Kuqa depression. There are two sets of coal-measure source rocks with large thickness, wide distribution, high organic content and high thermal evolution degree. The tectonic zone enjoys high hydrocarbon-charging intensity, which lays the foundation for large-scale accumulation of deep gas. The delta front of the Bashijiqike Formation in the Cretaceous System is widely distributed. The Kelasu tectonic zone is in the near end of delta front, and the micro-facies types mainly include underwater distributary channels and estuary dams. The sand bodies overlap with each other longitudinally and are connected with each other horizontally. They are stably distributed, and were buried rapidly in the late period. The huge-thick gypsum salt rocks effectively maintain the reservoir porosity. The structure has been sequeezed strongly. The natural fracture has developed. The combination of high-angle fractures, phaceloid porosities and linear pore throats has provided the foundation for high and stable production. The thickness of the two gypsum-salt-rock-covered areas in the Paleogene System and the Neogene System is between several hundreds of meters and several thousands of meters, the huge-thick salt rock is deeply buried, and the sealed-can effect occurs under the sequeezing conditions, so the highly-effective sealing is formed. The orogeny of Himalayan movement and the relatively simple squeezing background in the south-north direction are controlled by the huge-thick salt layer. The differential slipping of pre-salt Mexozoic structural layer has led to the relatively wide and flat superimposed thrust belt, and the deep structure is extended in line. The lower generation, middle accumulation and upper covering match with each other exactly in the aspects of time and space, and so do the structural evolution and oil/gas charging. Against the background that the sequeezing and lifting has occurred continuously and the deep pre-salt trap has been charged continuously, the accumulation conditions of extremely high pressure, large area and high enrichment degree have been created. Recently, guided by the understanding of accumulation mechanism, the exploration in deep clastic rocks has been intensified. The main body of the Kelasu tectonic zone basically controls the scale of Keshen-2 Gas Field, and the proven GIP almost reaches 3000×10^8 m^3; new findings have been obtained in Well Keshen-8, and the resource scale of natural gas reaches 1491×10^8 m^3; in the Awate Block in the western portion of thrust belt, important breakthrough has been made in Well Awa 3. At present, the newly-increased GIP of three classes in the keshen structural belt exceeds 8000×10^8 m^3, and the trillion-cubic-meter exploration area has gradually emerged. It is expected that as the exploration and development is intensified, the deep gas in Kuqa will make more contribution to the development of natural gas industry in China.

3.2.2.2. Carbonate rocks in Sinian-Cambrian System in the paleo uplift in Central Sichuan. The Sinian-Cambrian System in the Sichuan Basin is the most primeval oil and gas-bearing system in craton basin in China. Oilland gas exploration in this system commenced in the middle of 1950s, and till now near 60 years have elapsed. In 2011, after major finding in gas exploration in the Dengying Formation of Sinian System was obtained in Well Gaoshi 1, PetroChina carried out the integrated exploration and research on the Gaoshiti-Moxi structure [26] and identified a large gas-bearing area with a reserve of one trillion cubic meters. Comprehensive study of oil and gas geology revealed that the Sinian-Cambrian System in the Sichuan Basin has the favorable conditions for gas zones: several sets of karst weathering crust reservoirs have been formed owing to several tectonic movements since the Tongwan-Caledonian movement; the high-quality argillaceous source rocks have been formed owing to the rapid charging of Tongwan-period erosive ancient landform, so the source reservoir is of good configuration; the large-area beach-facies dolomite reservoir of the Longwangmiao Formation is distributed around the paleo uplift and developed; the paleo uplift which developed before the Late Yanshan Period serves as the favorable place for hydrocarbon migration and accumulation, so the large-area oil reservoir is formed; the overlapped area of the Moxi-Gaoshiti structures are enriched with hydrocarbon, and large-area lithological and stratigraphic gas reservoirs have developed in the slope of paleo uplifts.

It is predicted on the basis of the 2D and 3D seismic data of great Central Sichuan zone in the Sichuan Basin that, in Central Sichuan, the area with 20 m-thick reservoir stratum in the Longwangmiao Formation reaches 4350 km^2, so the exploration potential is huge; the two weathering crust karst reservoir strata in Deng-4 Member and Deng-2 Member of the Dengying Formation are widely distributed. In Deng-4 Member there is a structural and stratigraphical composite trap-type gas reservoir, which traps the favorable gas-bearing area of 4400 km^2 at an altitude of −5050 m and enjoys a huge exploration potential. As the exploration is intensified, the large gas-bearing area on the basis of Moxi-Gaoshiti structure and its slope belt may be identified. Thus, the large paleo uplift in the stable craton basin is the important target area for the identification of large gas fields, and against the background of paleo uplifts, the stratigraphical and lithological oil/gas reservoirs are still the important targets of oil and gas exploration.

3.2.2.3. Medium/deep clastic rocks in the Yinggehai Basin. The Yinggehai Basin is located in the South China Sea, to the west of Hainan Island and to the east of Indo-China Peninsula, where the depth of sea water is less than 100 m. It is a high-temperature and high-pressure Neozoic oil and gas-bearing basin which extends toward northwest, and is diamond shaped and covers an area of about 9.87×10^4 km^2. Research results revealed that [27−29] the Paleogene and Neogene areas in the Yinggehai Basin are large, with a thickness of sedimentary rocks reaching 17 km. Three sets of Eocene, Oligocene and Miocene source rocks are developed in a high-geothermal environment, with a geothermal gradient of 3.50−4.25 °C/100 m and a high thermal evolution degree. Source rocks are at the mature-high mature stage and are enriched with oil and much more gas. In this basin, the reservoir strata are highly developed. From bottom to top, there are seven reservoir strata, namely ancient Qianshan bedrock weathering crusts, Lingshan littoral sandstones, Shanya-Meishan neritic-facies sandstones, Shanya-Meishan neritic-facies sandstones & carbonate rock-based biogenic reefs, Huangliu marine sandstones, Yinggehai neritic-facies sandstones and Yinggehai marine turbidites. Since the Neogene Period, the faulty activity has not developed and the large-scale rising/lowering has occurred to the sea level, therefore, a large set of huge-thickness mudstones has deposited and acted as the regional caprocks, forming favorable conditions for hydrocarbon accumulation.

Before 2000, three gas fields, namely Dongfang-1-1, Dongfang-22-1 and Dongfang-15-1, were identified in this basin through oil and gas exploration, with the total proven GIP reaching 1606.64×10^8 m^3. Since 2000, the research on the accumulation and reservoir prediction of medium-deep oil and gas has been intensified. In 2010, the subsea apron-type high-quality reservoir stratum was found in Well Dongfang 1-1-14; in 2012, a gas reservoir was found in Member 1 of medium-deep Huangliu Formation in the Dongfang-13-2 Structure through exploration in Well Dongfang 13-2-1. The water depth of this gas reservoir is 64−70 m, and the buried depth of the target stratum is 2500−2650 m; the reservoir stratum is composed of Huangliu medium-deep subsea apron-type sandstone and is spindle-shaped. With an average porosity of 17%, an average specific permeability of 20−40 mD and a pressure coefficient of 1.68−1.82, this reservoir is a high-pressure gas reservoir. In 2012, the new proven GIP was 531×10^8 m^3, the accumulative proven GIP was 679×10^8 m^3, and the 3P reserves exceeded one hundred billion cubic meters. As a result, this reservoir is the largest gas field found in an independently-operated marine area in China. The results of recent appraisal revealed that, the subsea apron is widely developed in the medium-deep strata in this basin, so the medium-deep strata have huge exploration potential and will be the important area for gas exploration in this basin in the future.

3.2.3. Unconventional oil and gas

With the continuously rising international oil price, constantly grown oil and gas demand and great success achieved in the development of unconventional oil and gas resources in North America, the world has entered into a new period during which conventional oil and gas will enjoy a steady production increase and during which unconventional oil and gas will enjoy a rapid development [30]. In recent years, major breakthroughs have been made throughout the world in the exploration and development of unconventional oil and gas, including tight gas, coalbed gas, shale gas and tight oil, and the proportion of unconventional oil and gas output in the global total has been risen up to about 10%. In particular, with major breakthroughs successively made, shale gas and tight oil have become the typical representative in the development of unconventional oil and gas [31,32]. In 2012, shale gas output in the United States was 2710×10^8 m^3, accounting for about 40% of the total gas output in the country; tight oil output reached 0.97×10^8 t, accounting for about 22% of the total oil output in the country. The rapid development of unconventional oil and gas such as shale gas and tight oil has greatly reduced the United States' dependency on imported oil and gas. The exploration and development of unconventional oil and gas resources have drawn more and more attention, and have become the focus and hotspot throughout the world.

The specifical geological background for oil and gas in China paves the foundation and conditions for accumulation of unconventional oil and gas resources. Recent research results revealed that, tight oil and gas widely developed in China is controlled by 3 major geological factors: a. In the sand shale formations widely developed in China, clay shales and cleft stones are often overlapped and widely spread, and the developed clay shales have high hydrocarbon generation potential and high hydrocarbon expulsion efficiency, which serves as the foundation for the accumulation of tight oil and gas. b. The reservoir performance of tight reservoirs is mainly controlled by three major geological factors, namely sedimentary facies, diagenetic facies and fracture. c. Hydrocarbon generation, pressurization and microfracture communication (micro nano hole) are key to the accumulation of tight oil and gas. In China, unconventional oil and gas resources, especially tight oil and gas, have normally developed. For example, tight oil resources include Chang-7 Member of the Yanchang Formation in the Ordos Basin, the Permian Luchaogou Formation in Jimsar in the Juggar Basin, the Jurassic System in Central Sichuan in the Sichuan Basin, the Paleogene Shahejie Formation in the Jiyang Depression, the Hetaoyuan Formation in the Biyang Depression in the Nanxiang Basin and Teng-1 Member of the Alan Depression in the Erlian Basin; tight gas resources include Upper Palaeozoic Erathem in the Ordos Basin, the Xujiahe Formation in Upper Triassic System in the Sichuan Basin and the Yingcheng Formation in the Lower Cretaceous System in deep Songliao Basin; and shale gas resources include the Cambrian Qiongzhushi Formation in Southern Sichuan in the Sichuan Basin, etc. In recent ten years, breakthroughs have been made in the exploration of tight oil and gas in China, and tight gas has become the important contributor to the increase in natural gas reserve and output. The annual average new GIP is 3110×10^8 m^3, accounting for about 52% of the new proven gas reserve during the same period. In 2012, tight gas output was about 300×10^8 m^3, accounting for about 28% of the total gas output in China. Breakthroughs have also been made in the exploration of tight oil in the Sichuan Basin, the Junggar Basin and the Nanxiang Basin. With respect to coalbed gas, two production bases in southern Qinshui Basin and eastern edge of the Ordos Basin have been basically constructed. With respect to shale gas, commercial gas flow has been obtained in several wells drilled in the marine strata in southern Sichuan Basin, and major progress has been achieved in the construction of industrialized experimental zones. The above achievements fully show a bright prospect of exploration and development of unconventional oil and gas resources in China.

3.3. Natural gas markets and transportation in China

With the increasing energy demand in China, natural gas consumption has grown rapidly and continuously. Its proportion in primary energy consumption has been on the rise, and the proportion of imported natural gas in natural gas consumption has also increased rapidly. According to statistics, natural gas consumption in China has grown at an annual average rate of 16% since 2000 and reached 1471×10^8 m^3 in 2012. At present, gas consumption areas in China are changing from producing areas to larger areas. Gas consumption in economically developed regions such as Yangtze River Delta, Bohai Bay and southeast coastal areas accounts for 40% of the total gas consumption in China, and the consumption has covered all provincial capital cities. The proportion of natural gas in primary energy consumed also rose from 2.4% in 2000 to 5.4%, but still obviously lower than 24%, the world average level, and 11%, the Asian average level. In order to meet natural gas demand in China, the import volume of natural gas has increased rapidly, and the proportion of imported natural gas in natural gas consumed annually has also risen from 1.7% in 2005 to 28.9% in 2012.

It is found through analysis that rapid growth of natural gas consumption in China can be attributed to the following reasons: first, the energy utilization structure in China has been continuously optimized and the proportion of natural gas in energy consumption structure has been increased continuously; second, with the rapid development of national economy and people's improved living standards, the growth of gas consumption for domestic use has been accelerated, and the gas-using population has been increased from 25.81 million in 2000 to more than 200 million in 2012; third, new change has occurred to the natural gas consumption structure in China. Natural gas was mainly used in chemical industry and as fuel gas in the production of oil/gas fields. And now the proportion of natural gas used as urban fuel gas has risen from 18% to 39%; the proportion used as industrial fuel gas has lowered from 41% to 29%; the proportion used for power generation has risen from 4% to 18%; and the proportion used for chemical industry has lowered from 37% to 14%.

In China, the natural gas price reform has also been advanced steadily. Before 2010, the main mode of price reform for natural gas in China was to adjust the ex-factory price and pipe transmission price, but the gas price in China was still much lower than the comparable gas price in foreign countries and the price of imported gas. On December 26, 2011, the National Development and Reform Commission (NRDC) implemented the pilot experiment in Guangdong Province and Guangxi Zhuang Autonomous Region, changing the traditional cost-plus pricing method to the method based on net back pricing. In 2012, several gas pricing methods such as price linkage, comprehensive pricing and step-wise pricing were implemented in Anhui, Zhejiang, Sichuan and Nanjing. In addition, a natural gas spot trading platform was also launched in Shanghai.

At present, the infrastructures such as natural gas pipeline networks have constituted a system preliminarily. By the end of 2012, a batch of long-distance gas transmission trunklines, including West-to-East Gas Transmission Line, Sichuan-to-East Gas Transmission Line, Shaanxi-Beijing Gas Line, Zhongxian-Wuhan Gas Line and Shebei-Xining-Lanzhou Gas Line, had been constructed, with a total length exceeding 5.5×10^4 km and a total gas transmission capacity exceeding 1600×10^8 m^3/a. The nationwide gas supply network which extends from east to west and from south to north and connects with overseas pipelines has been formed basically.

In addition, the market pattern with diversified gas supply sources has been formed. At present, gas storage capacity of about 25×10^8 m^3 has been formed, accounting for 1.7% of the total gas consumption in China. Six LNG receiving terminals have been constructed, with LNG receiving capacity reached 1880×10^4 t/a in 2012. Seven LNG receiving terminals are being constructed now, and by 2015, the LNG receiving capacity in China will reach 4000×10^4 t/a.

4. Prospects of and challenges to natural gas industry in China

4.1. Prospects of natural gas industry development in China

The past 10 years are not only a period during which natural gas production in China has grown rapidly, but also a period during which natural gas industrial system in China has been gradually developed and improved. With respect to the development of natural gas industry, in 2012, the ranking of China in the aspect of proven and recoverable natural gas reserves was raised from No. 19 in 2000 to No. 13. The ranking in the aspect of natural gas output was raised from No. 16 in 2000 to No. 7, and the ranking in the aspect of natural gas consumption was No. 3 in the world.

It is expected that in the following 20 years, the demand for natural gas in China will still grow rapidly. According to a forecast by many concerned parties, in 2020 and 2030, the annual output of natural gas in China will be about 3500×10^8 m^3 and 5000×10^8 m^3 respectively. In the future, gas supply patterns based on domestic resources will be formed in China, and unconventional gas will become the important supply source. In 2020, the supply capacity will reach about 4000×10^8 m^3 and domestic output will exceed 2500×10^8 m^3, with the proportion of unconventional gas being 23%; in 2030, the supply capacity will exceed 5000×10^8 m^3 and domestic output will reach 3500×10^8 m^3, with the proportion of unconventional gas being 31%.

4.2. Challenges to natural gas industry development in China

With respect to the development of natural gas industry in China, there are both opportunities and challenges. Firstly, with the rapid development of national economy and the continuously-raised people's living standard, the demand for natural gas has increased continuously, which has created a favorable opportunity for rapid development of natural gas industry in China. Secondly, there is still relatively a large gap between natural gas output and demand in China. In the future, natural gas development will face the following challenges: a. the contradiction between rapidly growing demand and supply capacity will exist for a long term; b. the exploration and development of natural gas in China has become more and more difficult, and balanced importance should be attached to the development of conventional and unconventional gas; c. the volume of natural gas imported from foreign countries will increase rapidly, so the dependency on imported gas and the difficulty in supply guarantee will also increase; d. the infrastructures such as natural gas pipeline networks and gas storage depots have to be constructed; e. the pricing mechanism and management system for natural gas have to be improved and perfected.

4.3. Development strategy for natural gas industry in China

1) Natural gas should be taken as the main energy development object in China in 21st century. It has become a consensus that natural gas is a kind of clean energy, so it is necessary to further accelerate the development of natural gas industry in China, lay a firm foundation for the supply of natural gas resources in China, and make great efforts to develop and utilize the international natural gas resources, so as to fully improve the ability to guarantee the supply of natural gas.
2) China is relatively abundant with natural gas resources. It is necessary to increase the investment in gas exploration and development in China, attach balanced importance to the development of conventional and unconventional gas, and strengthen the theoretical research on gas exploration and development and the research and development of engineering technologies.
3) It is necessary to strengthen the exploration and purchase of overseas gas resources and establish stable gas trading and supply channels, so as to ensure gas supply security in China.
4) The construction of gas infrastructures is an important guarantee for sound development of natural gas industry. The government should provide support by granting preferential policies, and infrastructures such as nationwide natural gas pipeline networks and gas storage depots should be constructed as soon as possible, so as to create favorable conditions for a sustainable development of natural gas industry.
5) Price is the important factor which constraints the development of natural gas industry. The government should improve gas pricing mechanism as soon as possible, so as to promote the sound development of natural gas industry.

5. Conclusions and suggestions

On the basis of the above analysis, the following understandings are obtained with respect to the development of natural gas industry in China. (1) China is relatively abundant with oil and gas resources, so the reserves have increased continuously at high rate, and in the future, the oil and gas industry will still grow rapidly with further increased investment and strengthened technical development. (2) The distribution of oil and gas resources is quite uneven in China, and the lithologic formations, forelands, offshore carbonate rocks and mature exploration areas are still abundant with remaining oil and gas reserves and will be the focus for reserve increase. (3) The quality of oil and gas resources in China has deteriorated gradually, most of the new reserves are of medium or low quality, and it is expected that as the exploration expanded and exploration depth increased continuously, the costs of oil and gas exploration will increase obviously. (4) Tight oil/gas has become the focus of unconventional resources development. Some breakthroughs have been made in the exploration of tight oil and offshore shale gas, and the development of coalbed gas has been advanced steadily, which indicates a bright prospect of unconventional oil and gas development. (5) As the exploration expanded continuously, it has become more and more difficult. The increase of reserves has relied more and more on the advancement of theory and technologies, so the role of engineering technologies such as 3D seismic, horizontal well and fracturing has become more and more important. (6) With respect to the exploration potentials, stratigraphic oil/gas reservoirs, deep oil/gas reservoirs, offshore oil/gas reservoirs and unconventional oil/gas reservoirs will be the focus of exploration for finding large oil and gas fields in the future. (7) Unconventional oil and gas resources abound in China, and recently major breakthroughs have been made in unconventional oil and gas development. It is expected that with the continuous advancement of technologies, China will soon enter into an era of unconventional oil and gas development. As a result, it is necessary to borrow ideas from the advanced foreign experiences in the exploration and development of unconventional resources and organize relevant work in a scientific manner, so as to greatly promote the exploration and development.

In order to promote the rapid development of natural gas industry in China, the following suggestions are hereby made.

1) It is necessary to carry out an anatomical study and analysis on typical identified gas reservoirs (fields) carefully, especially focusing on typical gas reservoirs and the basic geological conditions of various gas reservoirs such as accumulation mechanism, so as to improve the understanding of natural gas accumulation.
2) China has carried out the appraisal and research on oil and gas resources for several rounds. In face of the new situations, it is necessary to organize a new round of appraisal and research on oil and gas resources of which the focus should be placed on unconventional oil and gas, so as to truly understand the resources in China.
3) Since the abundance of natural gas resources varies in various regions in China, it is necessary to intensify the evaluation on geological conditions and areas for natural gas accumulation, and properly select the favorable strata and zones for exploration.

4) Technologies have become the key factor which constraints natural gas development, so it is advised to make great efforts to develop horizontal well technology, reservoir fracturing technology and seismic technology in line with the geological characteristics in China (including equipment and professional team), so as to provide effective technical support for natural gas development.
5) In light of the fact that the overall quality of natural gas resources in China is relatively low, it is advised to explore into a new management mode for effectively organizing the development and utilization of low-quality resources, explore into a flexible management mode for small companies, improve the management system for exploration and production, and embark on the low-cost development.
6) It is necessary to implement technical innovation and delicacy management, explore into a large-scale, standardized and industrialized development mode, so as to minimize the exploration and production costs.
7) It is necessary to strengthen the cooperation and exchange with foreign oil companies, foreign service companies and international organizations, and borrow ideas from the internationally advanced experiences in production and management, so as to improve the level of exploration and development.

Acknowledgments

This paper is prepared on the basis of the speeches made by the authors on the annual conference of Natural Gas Committee under Chinese Petroleum Society in August 2013. Sincere gratitude is hereby extended to CNPC Economics & Technology Research Institute, Resource Planning Subinstitute under CNPC Exploration & Development Research Institute and Petroleum Geology Sub-institute under CNPC Exploration & Development Research Institute for their support and help in the preparation of this paper.

References

[1] CNPC Economics & Technology Research Institute. Report of the oil and gas industry development at home and abroad in 2013. Beijing: CNPC Economics & Technology Research Institute; 2014. p. 232−3.
[2] Jia Chengzao, Zhao Zhengzhang, Du Jinhu, et al. PetroChina key exploration domains: geological cognition, core technology, exploration effect and exploration direction. Pet Explor Dev 2008;35(4):385−96.
[3] Jia Chengzao, Zhao Wenzhi, Zou Caineng, et al. Geological theory and exploration technology for lithostratigraphic hydrocarbon reservoirs. Pet Explor Dev 2007;34(3):257−72.
[4] Zhao Wenzhi, Hu Suyun, Dong Dazhong, et al. Petroleum exploration progresses during the 10th Five-Year Plan and key exploration domains for the future in China. Pet Explor Dev 2007;34(5):513−20.
[5] Zhao Zhengzhang, Du Jinhu, Zou Caineng, et al. Geological exploration theory for large oil and gas provinces and its significance. Pet Explor Dev 2011;38(5):513−22.
[6] Jia Chengzao, Zheng Min, Zhang Yongfeng. Unconventional hydrocarbon resources in China and the prospect of exploration and development. Pet Explor Dev 2012;39(2):129−36.
[7] Guo Qiulin, Zhou Changqian, Chen Ningsheng, et al. Evaluation methods for unconventional hydrocarbon resources. Lithol Reserv 2011;23(4):12−9.
[8] Pan Jiping, Wang Nan, Han Zhiqiang, et al. Exploration and policy of unconventional gas resources in China. Int Pet Econ 2011;19(6):19−24.
[9] Hu Wenrui. Development and using of unconventional natural gas resources in China. J Daqing Pet Inst 2010;34(5):9−16.
[10] Zhao Wenzhi, Shen Anjiang, Hu Suyun, et al. Geological conditions and distributional features of large-scale carbonate reservoirs onshore China. Pet Explor Dev 2012;39(1):1−12.
[11] Zhang Baomin, Liu Jingjiang. Classification and characteristics of karst reservoirs in china and related theories. Pet Explor Dev 2009;36(1):13−29.
[12] Zhao Wenzhi, Wang Zecheng, Hu Suyun, et al. Large-scale hydrocarbon accumulation factors and characteristics of marine carbonate reservoirs in three large onshore cratonic basins in China. Acta Pet Sin 2012;33(S2):1−10.
[13] Wang Zecheng, Zhao Wenzhi, Hu Suyun, et al. Reservoir types and distribution characteristics of large marine carbonate oil and gas fields in China. Oil Gas Geol 2013;34(2):153−60.
[14] Kang Yuzhu. Conditions and explorative directions of marine giant oil-gas fields of Paleozoic in China. Xinjiang Pet Geol 2007;28(3):263−5.
[15] Zhang Shuichang, Zhang Baomin, Li Benliang, et al. History of hydrocarbon accumulations spanning important tectonic phases in marine sedimentary basins of China: taking the Tarim Basin as an example. Pet Explor Dev 2011;38(1):1−15.
[16] Zhu Guangyou, Zhang Shuichang, Zhang Bin, et al. Reservoir types of model marine carbonates and their accumulation model in western and central China. Acta Pet Sin 2010;31(6):871−8.
[17] Pang Xiongqi. Sedimentary characteristics and gas accumulation potential along margin of ordovician trough in western and southern parts of Ordos. Oil Gas Geol 2010;31(5):517−34.
[18] Yamg Hua, Fu Jinhua, Bao Hongping. Ordovician trough edge sedimentary characteristics and gas potential analysis of western and southern Ordos areas. Mar Orig Pet Geol 2010;15(2):1−13.
[19] Guo Yanru, Zhao Zhenyu, Fu Jinhua, et al. Sequence lithofacies paleogeography of the Ordovician in Ordos Basin, China. Acta Pet Sin 2012;33(S2):95−109.
[20] Fu Suotang, Huang Jiansong, Yan Xiaoxiong. New exploration realm of paleozoic marine carbonate rocks in E'erduosi Basin. Nat Gas Ind 2002;22(6):17−21.
[21] Zhao Wenzhi, Wang Zecheng, Zhang Shuichang, et al. Analysis on forming conditions of deep marine reservoirs and their concentration belts in superimposed Basins in China. Chin Sci Bull 2007;52(S1):9−18.
[22] He Dengfa, Li Desheng, Tong Xiaoguang. Stereoscopic exploration model for multi-cycle superimposed basins in China. Acta Pet Sin 2010;31(5):695−708.
[23] Li Benliang, Wei Guoqi, Jia Chengzao, et al. Some key tectonic characteristics of Chinese foreland basins and related petroleum geology. Geoscience 2009;23(4):575−86.
[24] Jia Chengzao, Wei Guoqi, Li Benliang, et al. Tectonic evolution of two-epoch foreland basins and its control for natural gas accumulation in China's mid-western areas. Acta Pet Sin 2003;24(2):13−7.
[25] Zheng Min, Jia Chengzao, Feng Zhiqiang, et al. Potential replacement regions of hydrocarbon reserves in exploration domain of foreland Basins. Acta Pet Sin 2010;31(5):723−8.
[26] Zhao Zhengzhang, Du Jinhu. The responsibility of geologists from the exploration practice. Beijing: Petroleum Industry Press; 2012. p. 26−34.
[27] Pei Jianxiang, Yu Junfeng, Wang Lifeng, et al. Key challenges and strategies for the success of natural gas exploration in mid-deep strata of the Yinggehai Basin. Acta Pet Sin 2011;32(4):573−9.
[28] He Jiaxiong, Xia Bin, Liu Baoming, et al. Gas migration and accumulation and the exploration of the middledeep layers in Yinggehai Basin, Offshore South China Sea. Pet Explor Dev 2005;32(1):37−42.
[29] Wang Zhenfeng, Pei Jianxiang. A new accumulation model of high pressure gas in Huangliu formation of the middle-deep interval in Yinggehai Basin: the significance of discovering a good-quality gas pay

with overpressure and high production in Well DF14. China Offshore Oil Gas 2011;23(4):213−7.
[30] Zou Caineng, Zhang Guangya, Tao Shizhen, et al. Geological features, major discoveries and unconventional petroleum geology in the global petroleum exploration. Pet Explor Dev 2010;37(2):129−45.
[31] Zou Caineng, Tao Shizhen, Yuan Xuanjun, et al. Global importance of "continuous" petroleum reservoirs: accumulation, distribution and evaluation. Pet Explor Dev 2009;36(6):669−82.
[32] Zou Caineng, Dong Dazhong, Wang Shejiao, et al. Geological characteristics, formation mechanism and resource potential of shale gas in China. Pet Explor Dev 2010;37(6):641−53.