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# Approach for natural gas to be a primary energy source in China

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**Abstract** This work reveals the positioning of natural gas in the evolution of world energy and the general law of its development. In the long-term adjustment of energy structure, natural gas has gradually become the primary energy source because of five factors: policy, resources, technology, facilities, and market. To expedite the revolution of energy production and consumption, China must urgently expand the use of natural gas toward a more positive role in complementing coal and renewable energy and prioritize its usage in three areas, namely, urban gas, power generation, and industrial fuel. Natural gas is expected to account for approximately 15% of China's total energy consumption in the future. For natural gas to be the primary energy, the exploitation of gas resources must be expanded, resource access must be improved, a flexible trade system must be set up, infrastructure investment must be increased, and the security system must be enhanced.

**Keywords** natural gas, energy revolution, primary energy, utilization areas, approaching means

## 1 Status of natural gas in world energy development

### 1.1 Forming process and developing trend of natural gas as primary energy

Over the past 200 years, social development and scientific

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and technological progress have brought profound changes to the world energy structure, which has experienced evolution from high-carbon to low-carbon and from single source to multiple sources. The primary energy has gradually changed from wood, coal, and oil to multiple low-carbon resources. In the 1940s, natural gas began to develop rapidly under the impetus of technological progress, resource exploitation, infrastructure construction, and other factors. In the 1960s, natural gas accounted for more than 20% of the primary energy consumption and therefore became one of the main energy sources in the world. In 2017, natural gas accounted for more than 15% of the total energy consumption in 30 out of 38 countries in the world whose total energy consumption exceeded 50 million tons of standard oil (with a ratio of 78.9%).

The development trend of world energy mainly shows the following four characteristics (Zou et al., 2016). First, coal development is entering a transitional period. Coal accounted for a declining share of primary energy consumption of 27.6% in 2017 (Fig. 1) (British Petroleum (BP), 2018). The utilization of coal will concentrate on power generation and chemical industry, developing toward centralized, clean, and efficient utilization. Second, oil development is stepping into a stable period. In 2017, oil accounted for 34.2% of the world's total energy consumption and remained as the world's most important energy source. The total oil consumption grew at an average rate of approximately 1.2% over the past decade. The development tendency of oil is projected to be stable in future. Third, new energy development is entering a golden period. In 2017, In addition to coal, oil and gas, other energy sources account for 14.8% of the total primary energy consumption, mainly with nuclear and hydropower accounting for 10.1%. New energy sources are growing rapidly, but from a very small base. The utilization of solar, wind, and geothermal energies accounted for 0.7%, 1.9%, and 1.0% of the total energy consumption in 2017, respectively. However, given energy storage limitations and other problems, these new energy sources are still facing difficulties in their rapid and

large-scale development. It will still take time before new energy becomes the primary energy source. Fourth, natural gas has stepped into the ranks of primary energy sources and entered the peak period of development. In 2017, natural gas has accounted for 23.4% of the world's primary energy consumption, which increased from 14.5% 60 years ago, making it the third largest source of energy after oil and coal. According to British Petroleum (BP) (2017) and forecasts from other institutions, the growth of natural gas consumption will remain the fastest among fossil fuels in the future, and global natural gas consumption will account for 25.2% of primary energy by 2035, which is comparable to those of coal and oil.

## 1.2 Status of natural gas in world energy development

### 1.2.1 Basic condition—long-term energy restructuring creates development opportunities

The shift in the world's energy structure is a long-term, clean, and low-carbon process. Taking the USA as an example, the transformation of the energy structure of the country took 55 years, from 1910 to 1965. The maturity of joint sealing and spot-welding technologies promoted the large-scale construction of natural gas pipelines in the USA in 1920 and laid the foundation for the development of natural gas. In 1938, the Natural Gas Law was promulgated to curb the monopoly of pipeline companies, and the government regulated the wellhead price of natural gas again in 1954, promoting the formation of a spot market of natural gas and leading to a rapid development of natural gas. Subsequently, the share of natural gas in primary energy rose from 5% to 31%, becoming the second largest

source of energy after oil in the country (Gao et al., 2017).

Natural gas is not completely dependent on national resource endowment to become the primary energy source. The history of energy evolution of most countries in the world indicates that (Table 1) coal-rich countries—such as the USA and Russia, which rank first and second in the world in terms of coal reserves, respectively—experienced a 40%–50% drop in coal consumption and a 25%–30% rise in natural gas consumption during the energy transformation period. UK and Japan, as coal-poor countries, have also experienced a coal share decline by 34% and 32%, respectively, whereas natural gas increased by 26% and 13% from scratch, respectively, during the energy transformation period. The growth and development of natural gas is a long-term process.

### 1.2.2 Driving factors—policy support, resource exploitation, technological progress, infrastructure, and market mechanisms

Government energy policy plays a leading role in natural gas development. The rapid development of natural gas is usually triggered by environmental issues, and then oriented and promoted by government energy and environmental policies. After the “haze incident” in London in 1952, a series of environmental protection policies, such as the Clean Air Act and Pollution Control Act, were introduced by the British government to accelerate the development of gas instead of coal. Since the 1960s, Japan has formulated strict environmental laws and regulations, such as the Basic Law on Environmental Pollution Control and Atmospheric Pollution Prevention Law, which have assisted in the energy reform and

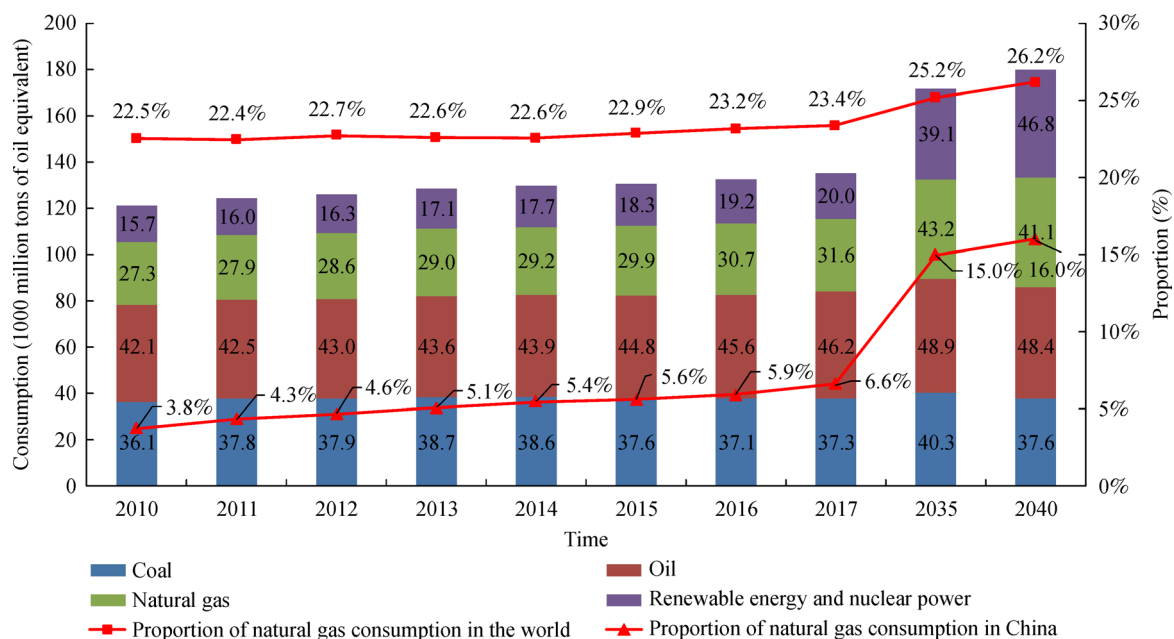


Fig. 1 Trends in world's energy consumption structure and natural gas share in 2010–2040 (British Petroleum (BP), 2017; 2018).

**Table 1** Energy evolution history of typical countries in the world

	Country	Coal reserves (100 million tons)	Coal reserves ranks	Coal consumption (100 million tons)	Coal consumption ranks	Energy transition period (Year)	Coal proportion changes (%)	Natural gas proportion changes (%)
Coal-rich countries	USA	2509	1	5.0	3	1910–1965	76 → 23	5 → 31
	Russia	1604	2	1.4	5	1950–1980	80 → 31	3 → 31
Coal-poor countries	UK	0.7	-	0.1	-	1965–1993	60 → 26	0 → 26
	Japan	3.5	-	1.8	4	1955–2003	55 → 23	0 → 13

promoted the rise of natural gas as the primary energy source (Gao et al., 2017).

Resource exploitation plays a fundamental role in natural gas development. Between 1945 and 1970, 185 gas fields were discovered in the USA, with an additional reserve of  $8.29 \times 10^{12} \text{ m}^3$ , thus accelerating the development of the natural gas industry in the USA. In the last decade, the large-scale exploitation of shale gas has pushed for the energy independence of the USA.

Technological progress plays a catalytic role in natural gas development. Technological progress has boosted the improvement of resource exploration, infrastructure construction, and natural gas utilization. Taking natural gas power generation as an example, Switzerland built the first 4-MW gas turbine with an efficiency of only 18%. However, in the 1980s, the combined gas-steam cycle technology increased the efficiency of gas turbines by over 50%, which significantly increased the natural gas usage in the power generation field. Natural gas power plants have been deployed rapidly and widely from scratch in the UK since 1986. The gas consumption for power generation increased from  $5.2 \times 10^8 \text{ m}^3$  in 1990 to  $3.2 \times 10^{10} \text{ m}^3$  in 2000, accounting for 70.8% of the increase in natural gas consumption. The share of natural gas power generation in the USA has also risen continuously since 1985, reaching 33% and surpassing the coal power generation for the first time in 2016.

Infrastructure plays a supporting role in natural gas development. Natural gas pipeline networks, storage facilities, liquefied natural gas (LNG) terminals, and other infrastructure are the foundations and pathways of expanding market coverage and scale. Taking pipeline construction as an example, the 1950s to the 1970s was the peak period of pipeline construction in the USA and also the rapid developing period of natural gas. The mileage of trunk pipelines in the USA increased from 175000 to 404000 km, with an annual increase of 11000 km. From the 1960s to the 1980s, Russia's natural gas trunk pipeline mileage increased from 20000 to 131000 km, forming a nationwide gas supply system.

The market and price mechanisms play a protective role in natural gas development. Establishing a mature market mechanism and implementing a reasonable price policy can help ensure the price advantage of gas and expand the

utilization of natural gas. Setting off with the price control policy in the UK, the price of natural gas is linked to but kept lower than the price of oil (Zhou and Wang, 2010). Later, the BP price index was established to promote the marketization of natural gas prices. Clean energy power generation is encouraged through a combination of carbon trading and carbon tax, also with differentiated environmental and fuel taxes.

1.2.3 Utilization of natural gas—industrial fuel and urban gas for the early stage, power generation for the late and rapid development stage

Natural gas's rapid development usually begins with the development of industrial fuel and urban gas. The natural gas consumption in the USA grew at an average annual rate of 7.1% during its rapid growing period. Industrial fuels and urban gas accounted for 80% of the natural gas consumption increase in the early stage of development. In the UK, industrial fuels and urban gas accounted for 86% of the increased usage of natural gas in the early stage of rapid development. At the beginning of Japan's rapid development period, natural gas was only used for power generation and urban gas. Urban gas usage increased by 34.8% from 1969 to 1983.

In the late stage of the rapid development period, natural gas power generation became the main growth force due to the continuous improvement of resource supply and gas power generation technology (Fig. 2). Since 1985, the USA has gradually replaced coal with natural gas for power generation. From 1987 to 2008, more than 90% of the newly deployed power plants have used natural gas. Since then, gas power generation has played an important role in grid-peak load regulation and has been a major component of distributed energy systems. In 2012, gas usage in power generation exceeded industrial consumption and jumped to the top of the natural gas consumption structure. In UK, after the breakthrough of gas turbine technology in the 1990s, approximately 65% of the natural gas usage increment was from gas power generation. By 2010, natural gas has accounted for 44.1% of the total power generation in UK. In Japan, electricity was mostly supplied by hydropower, oil, and coal before 1973. However, after the oil crisis, Japan turned to natural gas

and nuclear power and no longer built new oil power plants. By 2017, natural gas accounted for up to 33% of Japan’s gross power generation.

## 2 Role of natural gas in China’s energy revolution

### 2.1 Pushing the revolution of energy production and consumption

China’s gross energy consumption remains high, and the external dependence of energy resources is increasing annually. Severe environmental problems are receiving increasing attention from society. All these factors make the energy revolution imperative. Controlling the gross energy consumption, strengthening energy conservation, supporting the development of energy-saving and low-carbon industries, increasing the renewable energy usage, and building a clean, low-carbon, safe, and efficient energy

system should be the main tasks of energy production and consumption revolution.

Based on China’s energy situation and government requirements, the Chinese Academy of Engineering proposed a three-step strategy for energy revolution (Table 2), with “control air quality”, “control carbon emissions”, and “sustainable energy supply” as the corresponding starting points. According to this strategy, China will expedite natural gas utilization, optimize the energy structure, increase the proportion of clean energy, and gradually build an advanced energy system (The Comprehensive Group for Energy Consulting and Research, 2015). China’s energy is expected to reach the “5 peaks” successively in the future. These peaks are as follows: 1) The coal consumption will reach a peak of 2.8 billion tons of standard coal by around 2020; 2) The oil consumption will reach a peak of 900 million tons of conventional coal by around 2030; 3) The total energy consumption will reach a peak of approximately 6 billion tons of conventional coal in 2035; 4) The natural gas

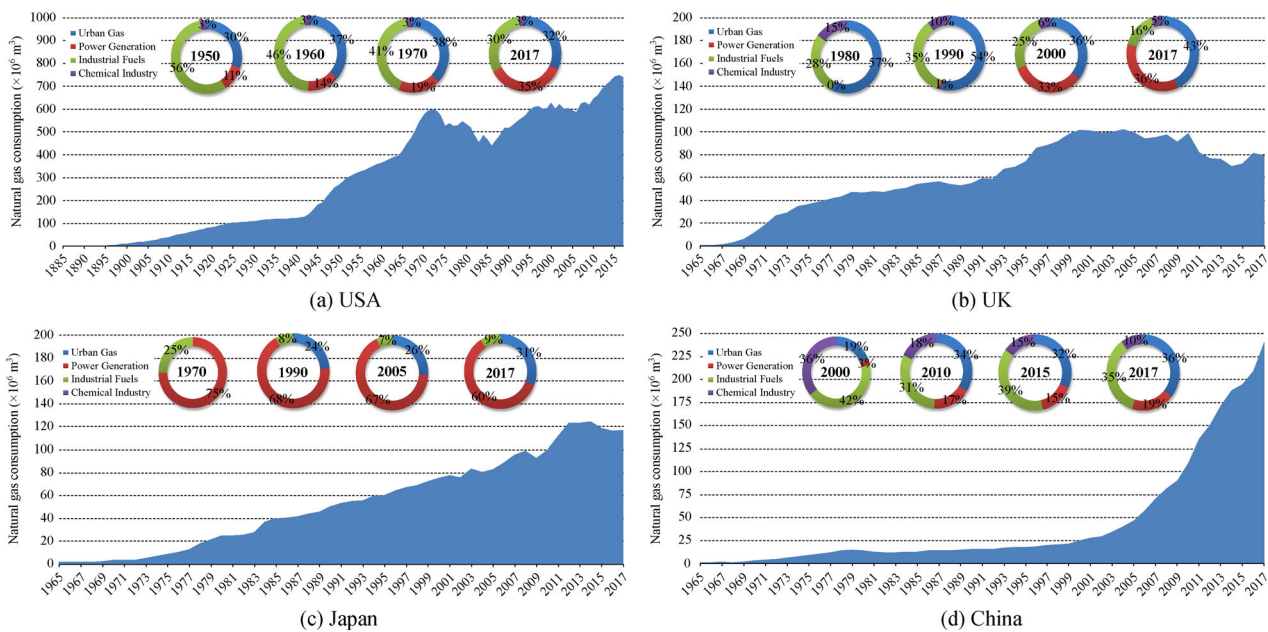


Fig. 2 Structural changes of natural gas utilization in China and other countries (British Petroleum (BP), 2018).

Table 2 Three-step strategy for the energy revolution in China

Time	Developing route	Goal
Before 2020	Take “control air quality” as the starting point to extend the use of natural gas and enable coal to reach its peak as soon as possible.	Increase the usage of natural gas and expedite the clean utilization of fossil fuels. Achieve an energy structure of 58% from coal, 17% from oil, 10% from natural gas, and 15% from non-fossil energy in 2020.
From 2020 to 2035	Take “control carbon emissions” as the starting point to expedite the development of low-carbon energy sources, such as renewable energy, nuclear power, and natural gas.	Build a balanced energy supply system that combines oil and gas, low-carbon energy, and clean coal. Achieve an energy structure of 45% from coal, 15% from oil, 15% from natural gas, and 25% from non-fossil energy in 2035.
From 2035 to 2050	Take “sustainable energy supply” as the starting point to reduce the dependence on fossil energy gradually.	Build an energy system that is half-non-fossil energy. Achieve an energy structure of 40% from coal, 14% from oil, 17% from natural gas, and 29% from non-fossil energy in 2050.

consumption will reach a peak of 950 million tons of conventional coal by around 2050; 5) Carbon emission will reach its peak by around 2030. In the future, natural gas will make a great contribution to the energy revolution in China as a clean energy source that complements the entire energy system.

## 2.2 Current status of natural gas resources and consumption in China

China possesses an abundant amount of natural gas resources, and its ability to maintain a stable supply has been continuously enhanced. In 2017, the remaining technically exploitable gas and shale gas reserves were 5522.1 and  $198.3 \times 10^9 \text{ m}^3$ , respectively, and the newly utilized natural gas and shale gas reserves were  $555.4$  and  $376.8 \times 10^9 \text{ m}^3$ , respectively, indicating a great potential for future production. In 2017, the domestic natural gas production in China was  $148.0 \times 10^9 \text{ m}^3$ , with an annual growth of 8.2%. In addition, the production of coal gas was  $2.63 \times 10^9 \text{ m}^3$ , with a year-on-year growth of 34.4%. The domestic production and supply capability are continuously increasing (Ministry of Natural Resources, PRC, 2018).

The natural gas consumption in China is growing rapidly due to multiple favorable factors. The consumption presents a trend that is not low during the off-season and is thriving during the peak-season. The total natural gas consumption in 2017 was  $238.6 \times 10^9 \text{ m}^3$  (Taiwan, Hong Kong, and Macao not included), with a yearly growth of 14.8%. Urban gas (36.0%) and industrial fuel (34.5%) are two major components within the entire natural gas consumption structure. The gas population coverage was approximately 350 million people in 2017, with an annual increase of 40 million. Six provinces, including Jiangsu and Sichuan, have broken through the  $10 \times 10^9 \text{ m}^3$  yearly natural gas consumption (The Oil and Gas Department of National Energy Administration et al., 2018).

## 2.3 Complement with coal and replenish shortage after coarse coal reduction

The concentration and clean utilization of coal are always part of the main measures of the energy revolution. However, the concentration utilization of coal in China is still low. In 2016, 1.24 billion tons of coarse coal was still used directly in China (National Bureau of Statistics, 2017). The emissions of nitrogen oxides, sulfides, and other atmospheric pollutants from coarse coal were approximately 15 times higher than the same amount of electric coal. By 2016, China's electric coal consumption only took 47.5% out of the total coal consumption, which was far lower than that of developed countries, such as the USA (95%), Germany (80%), and South Korea (70%). In

the future, coal will turn toward a centralized and clean utilization, mainly focusing on the power generation and coal chemical industry.

After the centralized utilization of coal, natural gas will be one of the most practical options to fill the shortage caused by coarse coal reduction. In 2016, the proportion of natural gas usage in the total industrial fuel consumption in China was approximately 10%, which was far lower than that in the USA (52%) and the UK (51%, including power generation), indicating high potential for development. Aiming at the shortage of coarse coal after the centralized utilization of coal, coal is estimated to account for 45% of the total energy consumption (6 billion tons of standard coal) in 2035. The proportion of electric coal will increase from 47.5% to 65%. If the coal consumption in cooking and washing remains stable, then the amount of coarse coal used for heating, industrial boilers/kilns, and people's daily consumption will be approximately 550 million tons in 2035. Thus, a reduction of 690 million tons of standard coal usage will be achieved from the number in 2016. If this coal usage reduction gap is replenished by natural gas and electricity, a new natural gas usage increment of approximately  $360 \times 10^9 \text{ m}^3$  will be obtained (Fig. 3).

## 2.4 Integrating with renewable energy to construct energy internet

In the future, the demand for electricity will continue to grow, and great opportunities for clean electricity will emerge. China's electricity demand will reach 11 trillion kWh in 2035 and 13 trillion kWh in 2050 (Table 3). Based on coal consumption control, clean energy power generation will reach 5.2 trillion kWh in 2035, accounting for 47.3% of the total power generation. Finally, this number will reach 56.9% in 2050. By 2035, renewable energy power generation is projected to be 4.2–4.4 trillion kWh, and gas power will reach 0.8–1 trillion kWh (Table 4).

The integration of natural gas and renewable energy has clear advantages, which will make natural gas an important part of the Energy Internet. Given the instability and lack of flexibility of renewable energy, the total abandoned electricity from wind, solar, and hydropower across China was about 100.7 billion kWh in 2017. In another word, approximately 12% of wind electricity and 6% of solar power were abandoned directly. The combination of natural gas and renewable energy will effectively improve the utilization level of renewable energy. Certain combined energy systems have already been applied within China and abroad. The Middletown Wind Farm in Denmark, which adopts wind photo voltaic-gas combined technology, is an example (Huang et al., 2019). China's Energy Internet construction should promote the integration of fossil energy and renewable energy and use natural gas to improve energy efficiency and enhance the level of energy security and supply stability.

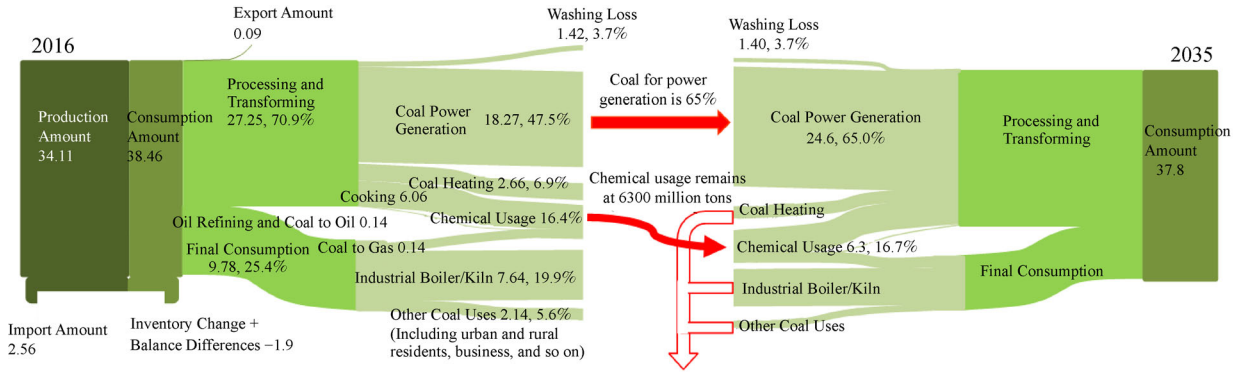


Fig. 3 Direction and scale of coal centralized utilization in 2035.

Table 3 Power demand forecast table from different institutions

Research institution	Forecast time (Year)	Electricity demand in 2020 (trillion kWh)	Electricity demand in 2030 (trillion kWh)	Electricity demand in 2050 (trillion kWh)
National Electric Power Planning Research Center	2017	6.8–7.2	10.0–11.0	12.0–15.0
State Grid Energy Research Institute	2017	7.0–7.6	9.1–11.0	14.3
National Energy Administration	2016	6.8–7.2	-	-
China Power Council	2011	-	10.3	12.0–13.0
Recommended power demand	-	7.2	10.0	13.0

Table 4 Future power supply composition table

Year	Coal electricity (trillion kWh)	Renewable energy, nuclear power, and others (trillion kWh)	Gas electricity (trillion kWh)	Gross electricity (trillion kWh)
2017	4.2	2.0	0.2	6.4
2020	4.7	2.3	0.3	7.3
2035	5.9	4.2–4.4	0.8–1.0	11.1
2050	5.6	6.2–6.4	1.0–1.2	13.1

### 3 Development and utilization direction of natural gas

Based on the national goal of controlling the gross energy consumption within 6 billion tons of standard coal by 2035, natural gas will take approximately 15% of the primary energy consumption of China by 2030, according to the government’s Plans on Accelerating Natural Gas Utilization. The demands of natural gas are anticipated to reach  $700 \times 10^9 \text{ m}^3$  annually by 2035 (National Development and Reform Commission, 2017). In the energy revolution, natural gas will play a vital role in two major ways, namely, complementing coal and replenishing the coarse coal reduction gap, to integrate with renewable energy to build Energy Internet. More specifically, natural gas will concentrate on urban gas, industrial fuels, and power generation.

#### 3.1 Urban gas

Natural gas has become the main source of urban gas in China. In 2017, China’s urban gas consumption was  $65.7 \times 10^9 \text{ m}^3$ , with population coverage of approximately 400 million. The urbanization rate, gas coverage rate, and gas consumption per capita still have a large gap compared with those of the USA, UK, and Japan (Table 5). By 2035, the population of gas coverage will be 800 million, at a rate of approximately 72%, and the gross heating area by natural gas will reach  $6 \times 10^9 \text{ m}^2$ . Gas, which is utilized in commercial sites and public service sectors, will account for approximately 50% of residential consumption. The detailed numbers project that the entire urban gas demand will reach  $155 \times 10^9 \text{ m}^3$  by 2035, including  $60 \times 10^9 \text{ m}^3$  for residents,  $30 \times 10^9 \text{ m}^3$  for commercial use, and  $65 \times 10^9 \text{ m}^3$  for heating purposes.

**Table 5** Urban gas development index table

Country	Urbanization rate (%)	Urban residents gas coverage rate (%)	Gas usage per capita (m <sup>3</sup> )
USA	80	90	770
UK	98	85	752
Japan	91	90	349
China	59	43	164

### 3.2 Industrial fuel

The application of natural gas as an industrial fuel is still low in China. In 2017, China's natural gas consumption as industrial fuel was  $76 \times 10^9 \text{ m}^3$ , which was approximately 32% of the total natural gas consumption. Natural gas only accounts for 10% of the total industrial fuel consumption. If industrial fuel coal usage is replaced by natural gas and electric power, considering the developing trend of "replacing coal by gas" and "replacing coal by electricity", the additional industrial demand for natural gas to replace coal usage is estimated to reach up to  $168.8 \times 10^9 \text{ m}^3$  in 2035, with a total demand of approximately  $240 \times 10^9 \text{ m}^3$  (Table 6).

### 3.3 Natural gas power generation

In 2017, China produced 6.3 trillion kWh of electricity, ranking first in the world, with 4.1 trillion kWh from coal, 1.6 trillion kWh from renewable energy, 0.2 trillion kWh

from nuclear power, and 0.2 trillion kWh from natural gas (3.2%). According to the requirements of atmospheric environment restriction and gross energy consumption control, coal power generation will reach 5.8 trillion kWh, and clean energy power generation will reach 5.3 trillion kWh in 2035 if the proportion of non-fossil energy consumption reaches 20% and coal for power generation increases from 47.5% to 65% (Table 7). The natural gas demand for power generation is expected to be  $200 \times 10^9 \text{ m}^3$  (with an increase of  $157 \times 10^9 \text{ m}^3$ ) by 2035.

### 3.4 Overall development scale of natural gas

The forecast indicates that the total scale of natural gas consumption in 2035 will be  $690 \times 10^9 \text{ m}^3$ , accounting for approximately 15% of the total energy consumption. Among them,  $155 \times 10^9 \text{ m}^3$  will be urban gas,  $240 \times 10^9 \text{ m}^3$  will be industrial fuel, and  $200 \times 10^9 \text{ m}^3$  will be power generation, accounting for 22%, 35%, and 30%, respectively, forming a "tripartite" structure of gas consumption.

**Table 6** Natural gas demand in industrial fuel area in the future

year	New demand for "gas replacing coal" ( $\times 10^9 \text{ m}^3$ )	New industrial demand ( $\times 10^9 \text{ m}^3$ )	Existing demand ( $\times 10^9 \text{ m}^3$ )	Total ( $\times 10^9 \text{ m}^3$ )
2020	40	4	76	120
2025	84	15	76	175
2030	100	29	76	205
2035	130	34	76	240

**Table 7** Future electricity generation structure demand table (trillion kWh)

Type	2017	2020	2035	2050
Coal power	4.1	4.7	5.8	5.6
Hydropower	1.2	1.2	1.5	1.8
Nuclear power	0.2	0.3	1.0	1.5
Wind power	0.3	0.4	0.9	1.2
Solar power	0.1	0.2	0.6	1.4
Gas power	0.2	0.3	1.0	1.2
Others	0.2	0.2	0.3	0.4
Total	6.3	7.3	11.1	13.1

## 4 Main tasks to make natural gas the primary energy in China

### 4.1 Establishing a stable natural gas system from the two relations and five dimensions

For natural gas to be the primary energy source, the entire industry chain must be strengthened from production and storage to final consumption. This process requires the proper handling of two major relations, namely, the relationship between domestic and international gas markets, and that between natural gas and the energy system within China. To achieve a reliable and secure natural gas system, the approaches from the five dimensions should be reinforced: resource availability, market capacity, price affordability, operational stability, and sustainable development (Fig. 4). Each dimension is explained as follows: 1) Resource Availability, make domestic resources the foundation, actively expand international purchase, and ensure a steady supply of gas resources; 2) Market Capacity, position natural gas correctly within the energy system for natural gas to develop under a reasonable market capacity; 3) Price Affordability, make the best use of the international price advantages of natural gas and establish a comparison system of natural gas price; 4) Operational Stability, improve the construction and operation level of the pipeline networks to enhance system stability and increase storage facilities; and 5) Sustainable Development, increase investment in supportive infrastructure systems and establish the strategy and route to achieve the

sustainable development of natural gas.

### 4.2 Strengthening domestic exploration and development of natural gas resources

China’s domestic gas reserve still has a considerable potential for growth. As of 2016, China has accumulated  $13.74 \times 10^{12} \text{ m}^3$  of explored conventional natural gas reserves, including  $544.1 \times 10^9 \text{ m}^3$  of shale gas. The recoverable resource of conventional natural gas in China is believed to amount to  $50 \times 10^{12} \text{ m}^3$ , among which are  $22 \times 10^{12} \text{ m}^3$  of shallow shale gas within 4500 m from the ground (Ministry of Land and Resources, PRC, 2017). Based on making natural gas the primary energy source in China, it’s necessary to emphasize carrying out the plan for domestic natural gas production while putting more effort into determining the possibility and measures of local natural gas exploitation under different oil prices and market situations.

The government must also establish an industry mechanism that allows legitimate entry and full market competition. Under the ultimate goal of better serving the country and the people, the domestic natural gas supply will experience a positive effect if the government reduces constraints on gas resource exploration.

### 4.3 Strengthening overseas resource acquisition

China’s dependence on foreign natural gas has increased rapidly, reaching 43% in the first half of 2018, which will further rise in the future. We should explore the possibility

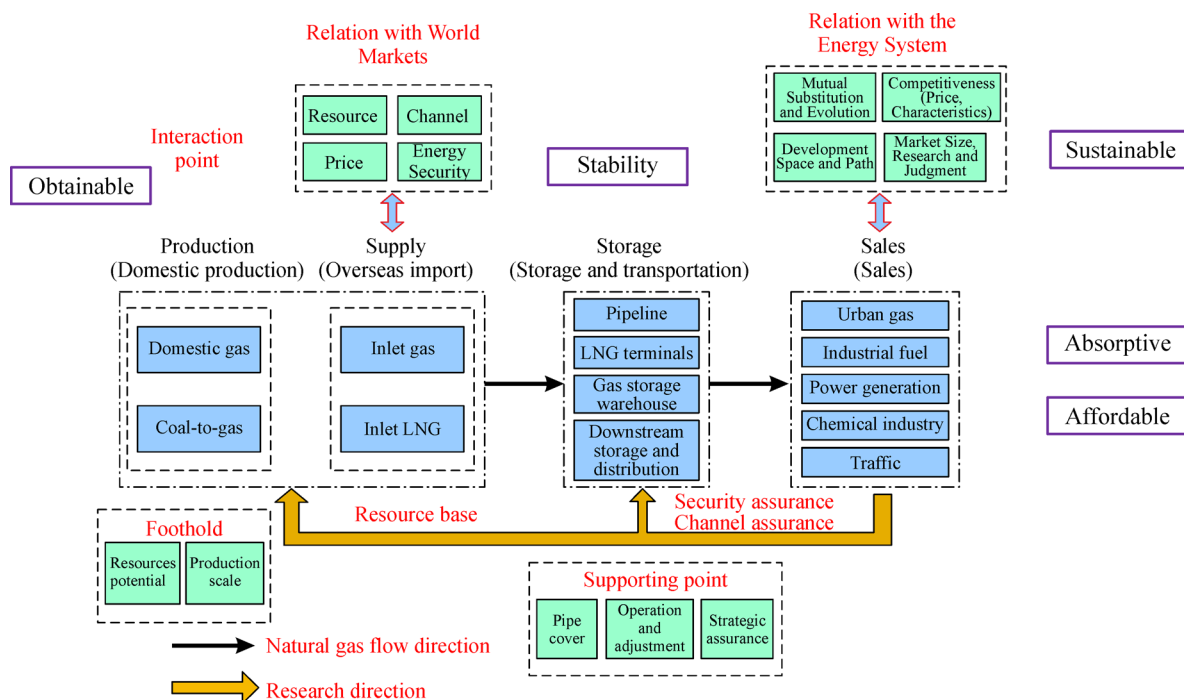


Fig. 4 Foundations of natural gas as primary energy and their interacting relations.

of participating in the global exploitation of natural gas while building a diversified natural gas supply system from overseas.

For security, we must continuously optimize the structure and arrangement of natural gas importation through marine and continental means to expedite the diversification process of importing sources, transportation methods, import channels, contract modes and importing entities.

#### 4.4 Expediting the establishment of the natural gas trading system

By 2035, China's natural gas imports are expected to account for approximately 20% of the world's natural gas trade. We should pay equal attention to overseas investment and importation trade, and long-term and spot contracts. We must also learn how to take full advantage of the peak demanding regulation effect of the spot market while increasing the stable long-term supply of natural gas. To set up a suitable natural gas trading system for China and keep up with the global gas industry, we must reasonably allot the imports through pipelines and LNG, establish a comprehensive price analysis mechanism, optimize the procurement channels of importation, and develop our own economical and balanced importing strategy while considering the source origins, scale, importing channels, prices, timing, gas supply pattern, and risks.

To accelerate the formation of the domestic natural gas trading market, we must promote the construction of natural gas trading centers in Shanghai and Chongqing, enabling these trading centers to play a role in price exploration and balance as soon as possible, and expedite the test project of natural gas marketization reformation in Sichuan and Chongqing. Trading rules and procedures must be completed and unified, the scope of transactions must be expanded, and the circulation of natural gas trading must be increased to form a nationwide natural gas price and trading system, which is composed of prices from different regions.

#### 4.5 Improving natural gas infrastructure

By the end of 2017, 74000 km of long-distance natural gas pipelines and  $7.7 \times 10^9 \text{ m}^3$  of underground gas storage facilities have already been built nationwide in China. By the end of 2030, the length of long-distance pipelines will exceed 200000 km, and the effective gas storage capacity will exceed  $60 \times 10^9 \text{ m}^3$ .

By expediting the construction of pipeline networks, expanding the scale of infrastructure, improving the distribution of pipeline networks, reinforcing the interactions between storage and transportation systems, building up an open and fair market, expediting the construction of

underground gas storage facility, improving the layout of LNG terminals, and establishing a more effective peak regulation system depending on the storage system, we will finally acquire a more reliable and secure natural gas system.

#### 4.6 Promoting the integrative development of natural gas with other energy sources

The Energy Internet exhibits the characteristics of multi-source energy inlets, free energy transmission, and open and fair source access (Rifkin, 2012), which dramatically helps break the barriers between different energy types of electricity, oil, gas, heat, and cold. It will also be the developing trend of future energy upon achieving the comprehensive utilization of energy.

Currently, natural gas has become an important contributor to renewable energy consumption (Huang, 2017) and an intelligent energy system within the Energy Internet. On the one hand, we should improve the energy efficiency and energy integration level to maximize the utilization of natural gas. On the other hand, we also need to expedite the research on the pipeline network layout and intelligent development of natural gas under the framework of Energy Internet.

#### 4.7 Completing research on natural gas development policy

For a better natural gas system, the establishment of a market system must be expedited, the price mechanism must be improved, industry management must be strengthened, and a stable and coordinated developing pace must be ensured. The regulators must also open up the upstream areas; build a unified and open natural gas market; strengthen the support on financial, fiscal, and taxation policies; release the price constraints on the competitive part of trading; push the reform on the supply-side, such as gas transmission and distribution; form a market-oriented natural gas pricing mechanism; establish demand-side management and early warning mechanism; and strengthen the industry supervision.

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