



**Asia-Pacific  
Economic Cooperation**

**FINAL REPORT**  
**Enhance Energy Utilization and  
Transformation Efficiency through  
Comprehensive Utilization of Coal**

**APEC Energy Working Group**

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## Introduction

*Enhance Energy Utilization and Transformation Efficiency through Comprehensive Utilization of Coal* under APEC Energy Working Group was applied by China Coal Information Institute. MR. Sun Qinggang as the contractor undertook a part of the tasks of the project. According to the requirements in the RFP of the project, the contractor conducted a series of on-site investigations for different coal comprehensive utilization models in China and Indonesia, as well as information collection for advanced experiences in developed economics. Based on data collation and analysis, the contractor has worked out a detailed and rigorously-structured project report, and developed an assessment tool of coal comprehensive utilization.

### **Background**

The problems of high consumption, pollution, emissions and low efficiency during coal processing exist in most of APEC economies. According to *BP Statistical Review of World Energy 2012*, coal consumption of APEC economies accounts for 76.9% of the world's coal consumption in 2011. In the primary energy consumption structure of major economies of the APEC, coal still occupies an important position, such as Australia 40.4%, Chile 17.1%, China 70.4%; 29.7% in Indonesia, Japan 24.7%, Korea 30.2%, 29.9% in Philippines, 21.7% in Malaysia, 37.9% in Chinese Taipei, Russia 13.3%, U.S. 22.1%, and Viet Nam 32.7%. Because of constraints of technology and awareness, APEC developing economies and part of developed economies don't fully utilized associated resources of coal and by-products in coal processing, such as kaolin rock, coal gangue, washing middling coal, coal slurry, mine water, the aluminum metal in coal gangue, fly ash in coal-fired power plant, low concentration coal mine gas etc. And it causes the low utilization efficiency and transformation efficiency of coal.

The *St. Petersburg Declaration* issued during the 10th APEC Energy Ministerial Meeting in Russia, 2012, suggests that improving the efficiency of energy is one of the most important means to ensure energy safety, economic growth and dealing with climate challenges. And the Declaration of the 19th APEC Economic Leaders' Meeting kicked off in Hawaii 2011 pointed out, "we have all been devoted to

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promoting our common goal for green growth. And we could and have to speed up the conversion to the global low-carbon economy, by strengthening the safety of energy and creating the new economic growth and employment sources”.

In October 2013, the *Bali Declaration* issued in the 21st APC Economic Leaders’ Meeting confirms to invigorate work to develop clean and renewable energy through public-private partnership, as a promising approach to ensure sustainable investment and development of new technology, and to promote energy security and efficiency and lowering of greenhouse gas emissions.

While the utilization of coal as raw materials with recycling technology rather than power fuel may integrate the materials and energies of different coal processing technologies by turning the waste of one utilization process into the other’s raw material and energy. This project will analyse the applicable scope of different technical route, and to explore the model of promotion in large scale to accelerate the clean and high-efficient utilization of coal in APEC. As a result, the project is expected to establish a coal comprehensive utilization model, for enhancing of coal utilization efficiency in APEC.

### **Objectives of the project**

The main objectives of the project include three points:

- a) Study the technological and economic feasibility and environmental and social benefits of different technological routes in a “Coal Comprehensive Utilization Model”;
- b) Pursue the right commercial development modes for the large-scale development of the Coal Comprehensive Utilization Model in the APEC region, and share experience on the effective coal cleaning utilization with coal-producing economies in the APEC region.
- c) Work out policies and suggestions for relevant government departments on the difficulties that pop up during the development and promotion of the recycling utilization of coal.

### **Significance of the project**

The implementation of the project will enhance the energy utilization with better

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transformation efficiency in APEC region, provide technical and support and political reference to emission reduction of GHG and energy conservation for developing economies in APEC region , and lay a foundation of stable energy supply, sustainable and safety energy production of APEC economies.

**Outline of the project report**

Part 1 coal resources and production consumption of the APEC economies, introduces the coal reserves, coal production and consumption of 21 APEC economies.

Part 2, investigation report indicates the current situation on coal comprehensive utilization of four domestic coal companies in China, the general situation of coal comprehensive utilization in Indonesia, and the advanced coal comprehensive utilization technologies and policy information in developed economies.

Part 3, Study on coal comprehensive utilization modes in APEC economies, analyzes and studies the comprehensive utilization modes of coalbed methane(CBM) and coal mine methane(CMM), coal gangue, fly ash and coal associated minerals, summarizes the advantages and disadvantages of the utilization modes, and puts forwards the challenges that APEC developing economies face.

Part 4, assessment model for coal comprehensive utilization, set up an index evaluation system and indicates the assessment process through case study.

Part 5, conclusion and suggestion, summarizes the general situation of coal comprehensive utilization on the basis of the previous parts, and put forwards policy suggestions for the promotion of coal comprehensive utilization.

## 1. Coal resources and production consumption of the APEC economies

### 1.1 Australia

#### 1.1.1 Coal reserves

Australia is rich in coal resources. According to BP statistics, as of the end of 2012, Australia had 76.4Gt of proved recoverable coal reserves (this includes 37.1Gt of proved anthracite and bituminous coal reserves, accounting for 48.61%, and 39.3Gt of sub-bituminous and lignite reserves, accounting for 51.4%), contributing 8.9% to the world's total proved recoverable coal reserves, ranking the 4<sup>th</sup> in the world next to United States, Russia and China. Given the present mining intensity, the proved recoverable coal reserves in Australia will be available for recovery for 177 years.

Australia has about 28 coalfields (Fig.1-1). Major coal basins include Bowen Basin in Queensland, Sydney Basin in New South Wales, Latrobe Valley and Gippsland in Victoria. High-quality coking coals are typically found in Sydney Basin and Bowen Basin. Sub-bituminous coal is mainly nestled in South Australia and West Australia. Lignite is principally distributed in Victoria where lignite contributes more than 96% to the total proved lignite reserves of Australia.

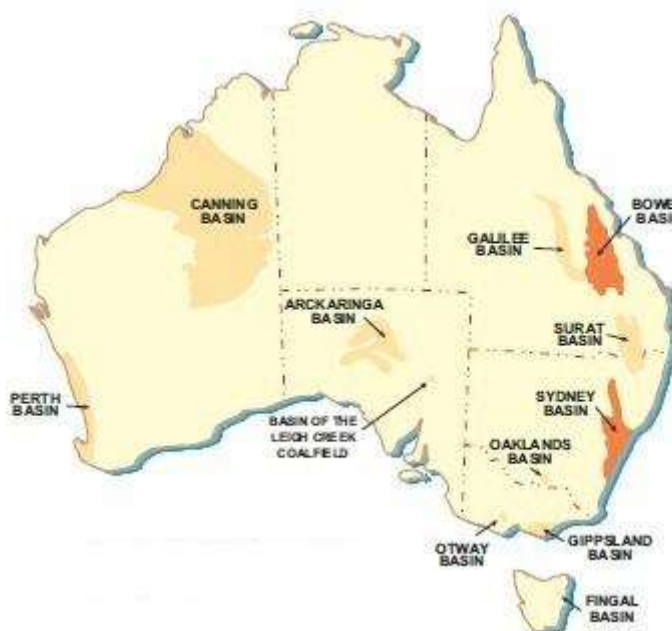


Fig.1-1 Location of coal basins in Australia



### **1.1.2 Coal production**

Existing coal mines in Australia total 107. Coal mining businesses are mostly operated in a polypoly pattern with international mining companies playing a critical role in the coal industry of Australia. The top 4 international mining companies in Australia are BHP Billiton, Xstrata, Rio Tinto Group and Anglo American, which together hold 53.04% of the total hard coal production. The fifth place is Peabody Energy from US, which owns 6 surface coal mines and 3 underground coal mines (5 in Queensland and 4 in New South Wales). Besides, it also has coal trade businesses in some of the important coal producing areas in Australia through Peabody Coal Trade. In 2010, Peabody Energy exported 27.0Mt of coal from Australia. In 2012, Australia reported 431Mt of raw coal production, up 16Mt from 2011 with an increase of 4.2%.

### **1.4.3 Consumption of coal resources**

Primary energy consumption in Australia is primarily coal, petroleum and natural gas, which took up 36.72%、36.04% and 23.09% in the primary energy consumption in 2010. Over the 45 years from 1965 to 2010, coal consumption in Australia recorded a year-after-year increase as whole with annual average increase of 2.69%.

The majority of Australia's hard coal is exported while lignite is consumed within Australia. Lignite mines are commonly seated close to power plants or pithead power stations. After the rapid increase in 1990-2005, lignite consumption has recorded small downfalls over the past few years, attributable mainly to competition from other fuels, especially natural gas, in Victoria.

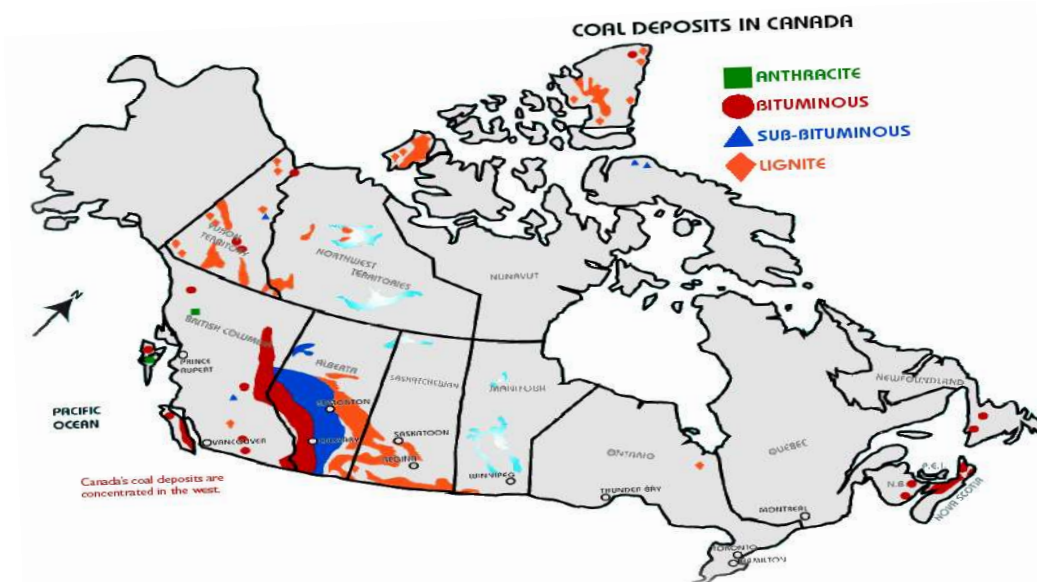
In 2007-2008, for instance, 75% of the power generation came from coal, and starting from the 1960s, the proportion of coal had been haunting around 60%~80%. The high proportion of coal suggests the cost advantage for power generation and the uniform distribution of coal-fired power generation bases in the highly demanded Southeastern Australia, with low-cost coal supporting the low power tariff. According to EP statistics, in 2012 Australia consumed 49.3Mtoe of coal (which was 1.3% of the world's total coal consumption), down 2.4Mtoe with a reduction of 4.9%.

## 1.2 Canada

### 1.2.1 Coal reserves

Canada is rich in coal resources and coal mining is typically by surface operation with hard coal production ranking the 14<sup>th</sup> place and hard coal export ranking the 7<sup>th</sup> place in the world. According to BP statistics, as of the end of 2012, Canada had 6.582Gt of proved recoverable coal reserves (this includes 3.474Gt anthracite and bituminous, accounting for 52.78%, and 3.108Gt sub-bituminous and lignite, accounting for 47.22%), contributing 0.8% to the world's proved recoverable coal reserves and ranking the 10<sup>th</sup> place in the world. Given the present mining intensity, the proved coal reserves in Canada will be available for recovery for 98 years.

Coal resources are primarily located in the British Columbia, Alberta and Saskatchewan of West Canada though a little proportion is also found in Nova Scotia and New Brunswick in the east. High-quality bituminous coal is primarily nestled at the British Columbia-Alberta boundary and in North British Columbia. Sub-bituminous coal is mainly found in South Alberta. Lignite is located in Saskatchewan. Fig.1-2 shows the distribution of coal resources in Canada.



Source: Coal Association of Canada

**Fig.1-2 Schematic showing the distribution of coal resources in Canada**

Geographically, coal-bearing regions are mainly at the eastern and western ends of Canada, the former hosting Paleozoic coal seams, while the Rocky Mountains in the west and its adjacent plains are home to Mesozoic and Neozoic coal seams.

### **1.2.2 Coal production**

So far, coal is produced in 6 provinces, with Alberta holding 49.3% of the total coal production, British Columbia 33.4%, Saskatchewan 16.8% and New Brunswick 0.5%. As of June 2010, there are 22 producing coal mines including 20 surface coal mines and 2 underground coal mines. In 2012, Canada produced 66.9Mt of coal, down by compared with the previous year with a reduction of 1.1%.

### **1.2.3 Consumption of coal resources**

Primary energy consumption in Canada mainly includes petroleum, natural gas and coal, which accounted for 32.3%, 26.7% and 7.4% of the total primary energy consumption in 2010.

Over the 18 years from 1991 to 2009, Canada recorded a stable rise amid fluctuation in its coal consumption as a whole. Domestic coal consumers in Canada are primarily power generation utilities. According to data published by Natural Resources Canada, in 2009, Canada consumed 55.5Mt of coal, including 50.0Mt for power generation, accounting for 90.1% of the total consumption, 3.0Mt for iron and steel production, accounting for 5.4%, and 2.0Mt for industrial applications, accounting for 3.6%. As of 2010, Canada had 24 coal-fired power plants which contributed 19% to the total power generation. According to EP statistics, in 2012 Canada consumed 21.9Mtoe of coal (which was 0.6% of the total coal consumption of the world), down by 0.4Mtoe compared with the previous year with a reduction of 2.2%.

## **1.3 People's Republic of China**

### **1.3.1 Coal reserves**

Coal is the basic energy and industrial raw material for China and coal industry is an important energy-based industry in China. Energy resources in China are characterized by rich in coal, poor in oil and short of gas, which decides that coal is not expected to change its role as the principal energy resources for China over a long period to come. Currently, China's dependence on imported petroleum is close to 60%. Consumption of natural gas increases every year. The relatively rich coal provides more than 70% of energy demands. According to the *China Mineral Resources* (2013) by Ministry of Land & Resources of PRC, in 2012, the newly discovered coal reserves reached 61.6Bt and four 5-billion-ton coalfields had been discovered. As of the end of 2012, the discovered coal reserves of China reached 1420Bt and with

proved reserves of 114.5Bt, ranking the third in the world next to only United States and Russia. The distribution of coal resources in China are illustrated in Fig.1-3.

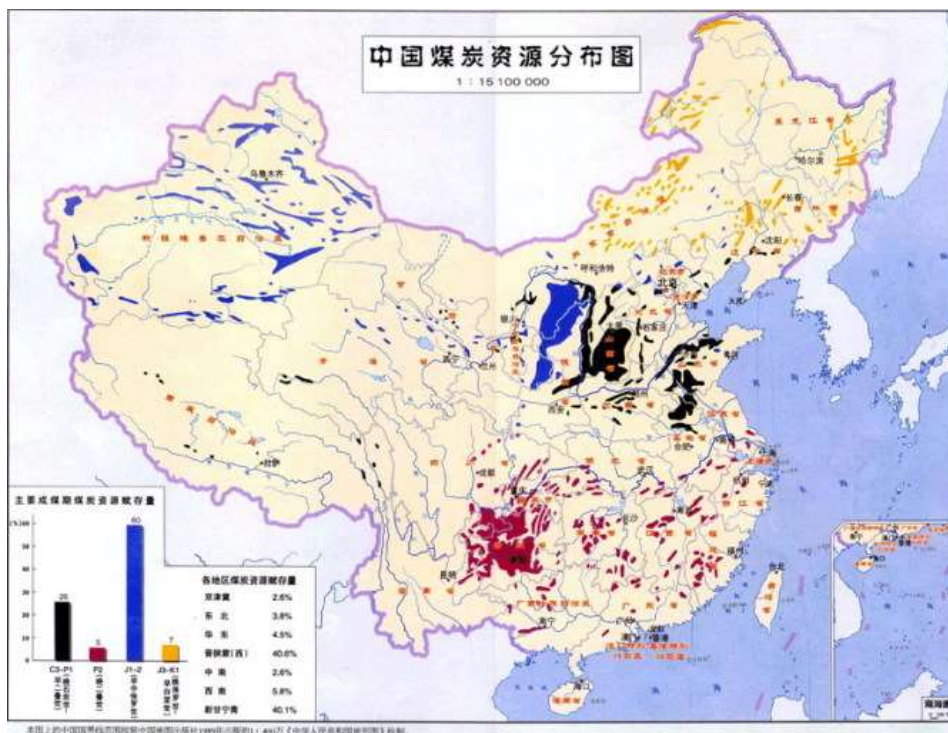


Fig.1-3 Distribution of coal resources in China

### 1.3.2 Coal production

According to the 12<sup>th</sup> five-year plan for coal development, effort will be focused on building large-scaled coal bases and groups. 14 large coal production bases across China will be accelerated to form ten 100-million-ton and 10 50-million-ton mega coal enterprises contributing 60% to the total coal production. The number of coal mines in China will be reduced to less than 10000. According to statistics, in 2012, China's large coal enterprises produced 2.73Bt of raw coals, increased by 188.311Mt from the same period of the previous year with a 7.4% increase. The aggregate output of the top 8 coal enterprises in China accounted for 30.2% of the total, up by 3.2% on year-on-year basis. The aggregate raw coal output of the top 10 enterprises in China was 1.47Mt, accounting for 53.78% of the total output of the large enterprises, and up by 140.221Mt on year-on-year basis with an increase of 10.6% (see Table.1-1). In 2012, China's coal output was 3650Mt, up by 124Mt from the same period of the previous year with an increase of 3.5%.

**Table.1-1 Statistics of raw coal output of China's top 10 large coal enterprises 2012**

	Enterprise	Raw coal output(Mt)	Increase (%)
1	Shenhua Group Corporation Limited	461.46	13.4
2	China Goal Coal Energy Company Limited.	175.52	7.3
3	Datong Goal Mine Group Co., Ltd.	132.67	15
4	Shandong Energy Group Co., Ltd.	122.92	13.6
5	Jizhong Energy Group Co., Ltd.	115.64	13.2
6	Shaanxi Coal And Chemical Industry Group Co., Ltd.	113.68	11.6
7	Shanxi Coking Coal Group Co., Ltd.	105.4	-4.2
8	Kailuan Group Co., Lt	83.54	18.3
9	Lu'an Group Co., Ltd.	80.08	3.8
10	China Yankuang Group Co., Ltd.	76.17	7.6

### **1.3.3 Consumption of coal resources**

The domestic economic increase slowdown has resulted in the operation difficulties of downstream industries, leading to surplus coal production capacity, excess output increase over demand increase, continued market slump, excess product supply over demand, excess inventory and continued decline of the sales prices. According to EP statistics, China consumed 1873Mtoe (million ton oil equivalent) of coal in 2012 (which was 50.2% of the world's total coal consumption), up by 113Mtoe from the same period of the previous year with an increase of 6.1%.

## **1.4 Indonesia**

### **1.4.1 Coal reserves**

Coal is a rich mineral resource in Indonesia. According to BP statistics, as of the end of 2012, Indonesia had 5.529Gt of proved recoverable coal reserves (this includes 1.520Gt of proved anthracite and bituminous reserves, accounting for 27.49%, and 4.009Gt of sub-bituminous coal and lignite, accounting for 72.51%), contributing 0.6% to the world's total proved recoverable coal reserves. Given the present mining intensity, the proved coal reserves in Indonesia will be available for recovery for 14 years.

Coalfields in Indonesia are mainly located in Sumatra and Kalimantan, and mostly concentrated in Central and South Sumatra, and Central, East and South Kalimantan, as shown in Fig.1-4. 46.6% of coal in Indonesia is produced from coalfields in Sumatra and 51.4% from coalfields in Kalimantan.



Fig.1-4 Distribution of coalfields in Indonesia

#### 1.4.2 Coal production

Since 1995, Indonesia has recorded fast growth in coal production. According to IEA, in 1973, Indonesia produced a merely 0.15Mt of coal. This increased to 41.15Mt in 1995, 75.6Mt in 2000 and 335.99Mt in 2010. In 2010, Indonesia produced 173.44Mt of hard coal, ranking the 7<sup>th</sup> in the world, and 162.55Mt of lignite, ranking the 2<sup>nd</sup> in the world. In 2012, Indonesia produced 386Mt of coal, up 32.3Mt from the same period of the previous year with an increase of 9%.

#### 1.4.3 Consumption of coal resources

Indonesia has recorded fast growth in coal consumption, from the 6.32Mt in 1990 to 49.195Mt in 2010. Main coal consumers are power generation, cement, metallurgy, papermaking and textile, with power generation consuming the most, about 81% of the total coal consumption. According to EP statistics, in 2012, Indonesia consumed 50.4Mtoe of coal (which was 1.4% of the world's total coal consumption), up 1.5Mtoe compared with the previous year with an increase of 2.8%.

## **1.5 Japan**

### **1.5.1 Coal reserves**

Japan is an island country covering a small area of land. It is poor in mineral resources with very limited recoverable reserves. According to BP statistics, as of the end of 2012, Japan had 350Mt of proved recoverable coal reserves (this includes 340Mt of anthracite and bituminous, accounting for 97%, and 10Mt of sub-bituminous and lignite, accounting for 3%). Given the present mining intensity, the proved coal reserves in Japan will be available for recovery for 265 years.

### **1.5.2 Coal production**

Despite its poor coal resources, coal has been mined in Japan for more than 200 years. Coalfields in Japan are mostly found in Hokkaido, Kyushu and Honshu. In 1940, Japan produced 56.3Mt of coal and marked the prime of the coal industry when the employee population was over 450000. However, starting from the 1960s, Japan's coal industry experienced a gradual decline due to the exhausted coal resources, competition from imported coal, rigid environmental and safety regulations and the extensive use of substitutes. Some measures were taken by the government to adjust the industrial structure and improve the efficiency and performance of the coal industry, resulting in gradual decrease in the number and output of coal mines. Starting from the mid-1980s, the coal industry pinched out and the few coal mines were closed successively. After Taiheiyo Coal Mine was closed in January 2002, the only coal mine left so far is Kushiro Coal Mine, with the purpose of supporting the research on coal mining technology and equipments. At present, Japan is the largest coal importer in the world and depends on imported coal for all its coal demands.

### **1.5.3 Consumption of coal resources**

As coal consumers in Japan are primarily iron and steel production and power generation, and coal imported typically includes power coal and coking coal. Over the past decade, coal for iron and steel production has remained generally stable, totaling 63.85Mt in 1995 and 65.35Mt in 2006. Despite some fluctuations during this period, the total coal consumption was not significantly different. In terms of the proportion in coal consumption, however, the proportion of coal used for iron and steel production has been on the fall, from the 49.01% in 1995 to 35.85% in 2006. Coal

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consumed for power generation changed significantly. In 1995, 41.41Mt of coal was consumed for power generation. In 2006, this increased to 82.22Mt, which was nearly twice as much. Coal consumed for power generation accounted for 45.11% of the total coal consumption from the 31.79% in 1995.

According to BP statistics, Japan is consuming more coal over the past years. In 1997, it consumed 89.8Mtoe of coal. In 2007, this increased to 125.3Mtoe, up 39.5% from 1911. In 2012, Japan consumed 124.4Mtoe of coal (which was 3.3% of the world's total coal consumption), up 6.7Mtoe from the same period of the previous year with an increase of 5.4%.

### **1.6 Republic of Korea**

#### **1.6.1 Coal reserves**

Coal resources in the Republic of Korea are almost all anthracite, with bituminous and lignite taking only a small proportion. Coal in Korea mostly dates back to late Carboniferous, with Permian/Triassic Ping'an formation and Miocene Hanmei strata of Datong formation s, with coal of Ping'an formation accounting for approximately 90%. Coalfields are mostly in the Gangneung – Haenam region of Tamakawa Geosyncline. According to BP statistics, as of the end of 2012, all anthracite in Korea had been recovered, leaving only 126Mt of proved recoverable coal reserves which are all sub-bituminous and lignite. Given the present mining intensity, the proved coal reserves in Korea will be available for recovery for 60 years.

#### **1.6.2 Coal production**

Starting from the 1990s, Korea learned from the experiences of highly mechanized coal mines in Australia, Canada and United States, and promoted forward coal mine modernization. In 2008, Korea had only 8 producing coal mines including 3 owned by Korea Coal Corporation and 5 private coal mines. The majority of these mines use inclined shaft development. In 2012, Korea produced 2.1Mt of coal, which was the same as the previous year.

#### **1.6.3 Consumption of coal resources**

Coal consumers in Korea mainly include power generation, iron and steel production and cement requirements. Over the past years, nearly half of the anthracite consumed



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has been for heating civil and commercial buildings. According to EP statistics, in 2012, Korea consumed 81.8Mtoe of coal (which was 2.2% of the world's total coal consumption), down by 1.8Mtoe from the same period of the previous year with a reduction of 2.4%.

### **1.7 Mexico**

#### **1.8.1 Coal reserves**

According to BP statistics, as of the end of 2012, Mexico had 1121Mt of proved recoverable coal reserves (this includes 860Mt of anthracite and bituminous, accounting for 71%, and 351Mt of sub-bituminous and lignite, accounting for 29%), contributing 0.1% to the world's total proved recoverable coal reserves. Coal resources are primarily located in Coahuil of northeast Mexico and Oaxaca in the south. Given the present mining intensity, the proved coal reserves in Mexico will be available for recovery for 88 years.

#### **1.7.2 Coal production**

In 2012, Mexico produced 13.8Mt of coal, down by 0.7Mt from the previous year with a reduction of 0.2%.

#### **1.7.3 Consumption of coal resources**

Petroleum and natural gas hold the first places in the primary energy consumption of Mexico, accounting for 57.4% and 31.3%, respectively. Next to them is coal, which accounts for 5.9%, nuclear power 1.5%, and water energy 3.9%. According to EP statistics, in 2012, Mexico consumed 8.8Mtoe of coal (which was 0.1% of the world's total coal consumption), down by 0.1Mtoe from the same period of the previous year with a reduction of 0.7%.

### **1.8 New Zealand**

#### **1.8.1 Coal reserves**

New Zealand has lignite, sub-bituminous and a fraction of high-quality bituminous resources. Lignite is primarily located in Central Otago and Southland in the South Island. Both South and North Islands contain sub-bituminous, with Westcoast of South Island containing a fraction of high-quality bituminous coal. According to BP statistics, as of the end of 2012, New Zealand had 571Mt of proved recoverable coal

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reserves (this includes 33Mt of anthracite and bituminous, accounting for 6%, and 538Mt of sub-bituminous and lignite, accounting for 94%), contributing 0.1% to the world's total proved coal reserves. Given the present mining intensity, the proved coal reserves in New Zealand will be available for recovery for 115 years.

### **1.8.2 Coal production**

The major coal company in New Zealand is Solid Energy, which is a state-owned company. There are also some minor coal companies and coal mines. In 1999, Solid Energy exported 1.2Mt of coal. Over the fiscal year from July 1, 2002 to June 30, 2003, the company exported 2.1Mt of coal, which was more than half of the total coal production and accounted for 90% of the total coal export. In 2012, New Zealand produced 4.9Mt of coal, which was roughly the same as the previous year.

### **1.8.3 Consumption of coal resources**

New Zealand is a small country in South Pacific with a population of about 3 million. Given the production intensity, the coal resources will be available for use for 1000 years. Coal produced is primarily used for civil and base industrial purposes. According to EP statistics, in 2012, New Zealand consumed 8.8Mtoe of coal (which was 0.1% of the world's total coal consumption), down 0.1Mtoe from the same period of the previous year with a reduction of 0.7%.

## **1.9 Peru**

In 1859, private coal mining started in Region VIII Lota in the south, making Lota the industrial center of Chile with more than 200 coal-carrying ships arriving at the port. In 1859, the Region VII also started coal mining and refining. In 1970, Chile established companies and nationalized the private businesses. During 1979 to 1981, the two coal companies were producing 0.5Mt of coal but the high production cost, plus inadequate technical input and the low international market prices, had always remained a challenge. In 1996, the production cost of ENACAR was 140 US dollars per ton, compared to the 57 US dollars per ton for imported coal. The heavy deficit has led to the successive close-up of the ENACAR coal mines over the decade afterwards. In 2011, ENACAR sold out its remaining stock and officially started liquidation this April. In 2013, after compensating over 2400 employees, the

ENACAR board of directors officially decided to start liquidation, thus putting an end to the 161-year coal mining history of Chile.

According to EP, in 2012, Peru consumed 0.8Mtoe of coal, up 0.1Mtoe from the same period of the previous year with an increase of 6%.

## **1.10 The Russian Federation**

### **1.10.1 Coal reserves**

The Russia Federation ranks the second in the world by coal resources. According to BP statistics, as of the end of 2012, Russia had 157.01Bt of recoverable coal reserves, accounting for 18.2% of the world's total. Given the present mining intensity, the proved recoverable coal reserves in Russia will be available for recovery for 433 years.

Russia has all coal types ranging from long-flame coal to lignite. Among the proved recoverable reserves of various types, lignite contributes 51.2%, bituminous 45.4% and anthracite 3.4%. The lignite has ash content of 6%~10% and sulfur content of 0.2%~0.6%. Coking coals, which provide both huge reserves and all necessary varieties to allow for iron and steel production, are mostly found in Kuzbass, Pechora, South Yakutia and Irkutsk Coalfields.

The coal reserves in Russia are extremely asymmetric in their distribution, with more than three quarters located in its Asian part and a quite limited proportion in its European part. 90%-95% of its coal reserves are located east of the Urals, dominantly in Siberia, contributing more than 90% to the reserves in the east, while the reserves in its European part taking merely not more than 10%.

The coal resources of Russia are distributed in 22 coalfields, including Kuzbass Coalfield, Kansk-Achinsk Coalfield, Irkutsk Coalfield in Siberia, South Yakutia Coalfield in Far East, and Pechora Coalfield in the north part. Coking coals are produced in Kuzbass, Pechora, South Yakutia and Irkutsk Coalfields while lignite is produced in Kansk-Achinsk Coalfield

### **1.10.2 Coal production**

Starting from 2000, Russia has reported continuous increase in its coal mining. In 2008, the country produced 329Mt of coal, ranking the 5<sup>th</sup> in the world next to only China, United States, India and Australia, with coking coal production of 68.7Mt. In 2012, Russia produced 354Mt of coal, up by 19Mt compared with the previous year with an increase of 6.1%.

### **1.10.3 Consumption of coal resources**

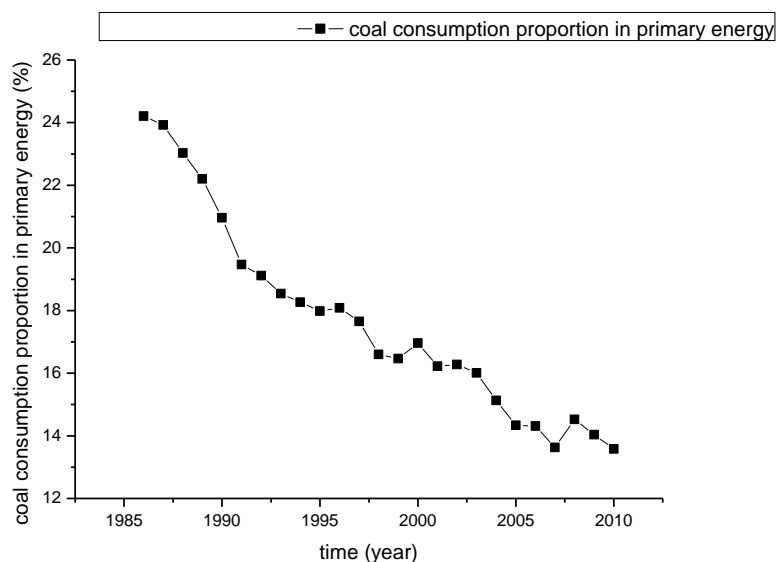
Coal has always been an important source of energy for Russia. After the October Revolution up to the 1950s, the former Soviet Union had stuck to an energy policy that gave the first priority to coal development, which was generally able to accommodate the coal demand for the national economy. By 1950, coal was taking an absolutely dominant position by holding 77.2% of the energy production of the former Soviet Union. The early 1950s to the mid-1970s witnessed a great transform in the energy policy of the former Soviet Union, when priority was given to petroleum and natural gas and many energy consumers started to use oil and gas in place of coal quickly, causing steep rises in the proportion of oil and gas consumption, and the dominance of oil and gas in place of coal. In 1963, the production of oil and gas together exceeded that of coal and held 50.1%. Ever since then, petroleum and natural gas have taken the leading position in the energy production of the former Soviet Union while the proportion of coal has kept falling. As of the beginning of the 1980s, the proportion of coal in the energy production of Russia had fallen to 20%. In the 1990s, it was only 12%-13%. Since 2000, despite the year-after-year increase in coal production, no significant rise has been seen in its proportion in the total energy production. See details in Fig.1-5.

As Siberia and Far East is poor in petroleum and natural gas, coal-fired boilers take up 90%. In some of the large geographical economic regions including Siberia, Far East and Ural, coal is still the dominant fuel. In a few areas, such as Primorye in Far East, which has long been short of fuel supply, coal is still playing an extremely critical role. Details are given in Fig.1-6.

Coal consumers in Russia mainly include electric power and metallurgical businesses, with coal-based power generation accounting for more than 30% of the total power generation. In 2009, Russia consumed 206.1Mt of coal, including 112.6Mt for power

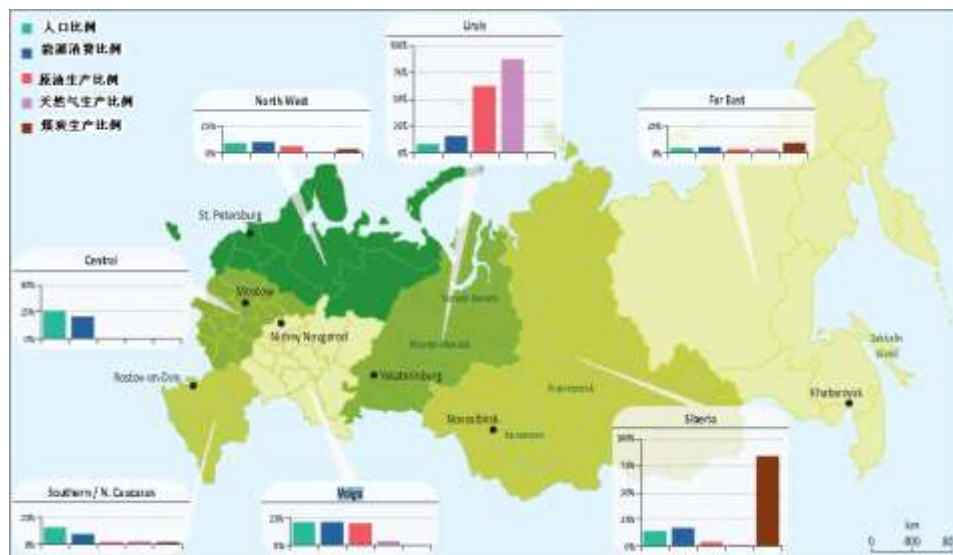
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generation, 38Mt for coking, 24.4Mt for domestic application and 31.1Mt for other purposes. According to EP statistics, in 2012, Russia consumed up to 93.9Mtoe of coal (which was 2.5% of the total coal consumption in the world), up 0.2Mtoe from the same period of the previous year.



Source: BP Statistical Review of World Energy June 2011

**Fig.1-5 Coal consumption proportion in primary energy in the Russian Federation 1986-2010**



Source: World Energy Outlook 2011

**Fig.1-6 Schematic showing the population, energy consumption and mineral production proportion of Russia by region in 2009**

人口比例 % population      能源消费比例 % energy consumption  
 原油生产比例 % crude oil production      天然气生产比例 % natural gas production  
 煤炭生产比例 % coal production

## 1.11 Thailand

### 1.11.1 Coal reserves

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According to BP, as of the end of 2012, Thailand had 1239Mt of proved recoverable coal reserves which are all sub-bituminous and lignite, accounting for 0.1% of the world's total proved recoverable coal reserves. About 80% is located in Chiang Mai, Lamphun, Tak, Phrae and Uttaradit of North Thailand, and the remaining is contained in Surat Thani, Trang, Krabi in the south, and Korat and Kalasin in the northeast. Given the present mining intensity, the proved coal reserves in Thailand will be available for recovery for 68 years.

### **1.11.2 Coal production**

In 2012, Thailand produced 18.3Mt of coal, down by 3Mt from the previous year with a reduction of 14.3%.

### **1.11.3 Consumption of coal resources**

At present, coal consumers in Thailand are mainly power generation and civil uses. As the heat stability is too low for furnace gasification, coal gas is rarely seen. According to EP statistics, in 2012, Thailand consumed 16Mtoe of coal (which was 0.4% of the world's total coal consumption), which was the same as the same period of the previous year.

## **1.12 United States**

### **1.12.1 Coal reserves**

United States is rich in coal resources, and coal is typically mined by surface operations with hard coal production ranking the world's 2<sup>nd</sup> and hard coal export in the 4<sup>th</sup> place. According to BP statistics, as of the end of 2012, United States had 237.3Gt of proved recoverable coal reserves, ranking the first place in the world with 27.6% of the world's total proved recoverable coal reserves. Given the present mining intensity, its proved recoverable reserves will be available for recovery for 239 years. Among the proved recoverable reserves, anthracite and bituminous contribute 45.72%, and sub-bituminous and lignite contribute 54.28%.

By geographical location, the distribution area of coal resources in the US can be divided into three regions: the Appalachian in the east, Interior and Western regions. The Appalachia Coal Basin dates back to in 220~320Ma and belongs to Permian Pennsylvanian series. The Interior and Western coalfields are 33~1400Ma old and

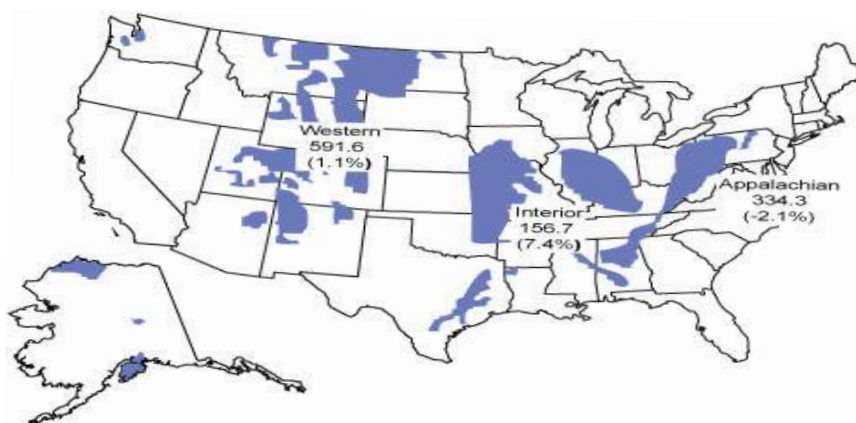
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belong to Cretaceous and Tertiary. Coalfields in Alaska belong to Jurassic and date back to 135~175Ma. The Appalachian in the east, Interior and Western regions contribute 22.6%, 28.1% and 49.3%, respectively, to the total proved coal reserves of the country.

Geographically, while coal has been found in 38 states, the coal reserves of the US are mostly concentrated in Colorado, Illinois, Montana, Pennsylvania, Ohio, West Virginia, Wyoming and Kentucky, which hold 84% of the total proved coal reserves, with Montana holding 25.4% of the total proved coal reserve, Wyoming 14.8% and Illinois 14.3%.

Major coal basins in the US include Appalachian Coal Basin, Illinois Coal Basin, Midwest Coal Basin, Fort Union Coal Basin, Powder River Coal Basin, Wyodak Coal Basin, Green River Coal Basin, San Juan Coal Basin and upper Colville Coal Basin. Two coal basins with the highest development intensity and largest reserves are the Appalachia Coal Basin in the east and Power River Coal Basin in the west.

### 1.12.2 Coal production



**Fig.1-7 Schematic showing the location of main coal producing areas in United States**

Coal producing areas in the US include Appalachian, Interior and Western coal producing areas (see Fig.1-7), accounting for 30.8%, 14.4% and 54.8% of the s total coal production, with the west coal producing area contributing 54.5% of the total coal production. Statistics of the coal production from major coal producing areas is shown in Table.1-2.

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Major coal mining businesses in the US include Peabody Energy, Arch Coal Inc., Cloud Peak Energy and Alpha Natural Resources Inc. Peabody Energy is the largest coal producer in the US with coal production accounting for 17.6% of the total coal production. The second largest one is Arch Coal Inc. which contributes 13.8% to the total coal production. The third largest one is Cloud Peak Energy, a wholly-owned subsidiary of Rio Tinto in the States, which holds 8.5% of the total coal production. The fourth one is Alpha Natural Resources Inc. with coal production accounting for 5.4% of the total production. In 2012, United States reported 922Mt of coal production, down by 71Mt from 2011 with a reduction of 7.5%.

**Table.1-2 Statistics coal output of main coal producing areas in United States 2006-2010 in MST**

Main producing area	2006	2007	2008	2009	2010
Appalachia	391.2	377.8	390.2	341.4	334.3
East Appalachia	136.2	132.1	135.6	126.2	129.2
Central Appalachia	236.1	226.2	234.0	196.5	184.9
South Appalachia	18.8	19.3	20.6	18.8	20.2
Center	151.4	146.7	146.6	145.8	156.7
West	619.4	621.0	633.6	585.0	591.6
Tailing recovery	0.8	1.2	1.4	2.7	2.8
Total	1162.8	1146.6	1171.8	1074.9	1085.3

Note: MST is the acronym of million short tons.  
Source: U.S.EIA

### 1.12.3 Consumption of coal resources

Primary energy consumption in the US mainly includes petroleum, natural gas, coal and nuclear energy, which accounted for 37.18%, 27.17%, 22.95% and 8.41% of the primary energy consumption in 2010. In 2010, the US consumed 1048.3Mst of coal. Coal consumers mainly include the electric power industry, other industries, coking plants and civil consumptions, accounting for 93%, 2%, 4.6% and 0.4% of the total coal consumption. According to EP statistics, in 2012, United States consumed 437.8Mtoe of coal, down by 57.7Mtoe from the same period of the previous year (which was 11.7% of the world's total coal consumption) with a reduction of 11.9%.



## **1.13 Viet Nam**

Over the past years, Viet Nam has reported fast growth in coal production and become the third largest coal producer in Southeast Asia and the third largest anthracite producer in the world. In 2010, Viet Nam exported 22.4Mt of hard coal, ranking the 9<sup>th</sup> in the world. Viet Nam has a complete legal framework in place for mineral resources development and for foreign capital investment. Its domestic coal consumption is mainly for power generation purposes.

### **1.13.1 Coal reserves**

According to BP statistics, as of the end of 2012, Viet Nam had 150Mt of proved recoverable coal reserves, which are either anthracite or bituminous. Given the present mining intensity, the proved coal reserves in Viet Nam will be available for recovery for 4 years.

Coal resources are located across Viet Nam, though they are primarily contained in Quang Ninh and Red River Coalfields. The coal types include anthracite, sub-bituminous, peat coal and fat coal. Fat coal is typically used for metallurgical applications but the reserves are very limited.

### **1.13.2 Coal production**

Producing coalfields in Viet Nam are Quang Ninh and Red River Coalfields. A project under construction is Ha Lam Coal Mine. In 2012, Viet Nam produced 41.9Mt of raw coal, down 2.6Mt from the same period of the previous year with a reduction of 6.1%.

### **1.13.3 Consumption of coal resources**

Primary energy consumption in Viet Nam mainly includes petroleum, coal and natural gas, which accounted for 35.45%, 31.14% and 19.09% of the primary energy consumption in 2010. Domestic coal consumption is dominantly for power generation. Coal is also used as building material as well as important fuel for chemical industry, transport and food processing. Domestic coal consumers include thermal power plants, cement plants, fertilizer plants, ceramic plants, papermaking, textile and other industrial applications. Besides, coal is also a household fuel for the urban and rural population. In 2010, Viet Nam consumed 23.2Mt of coal, which was approximately

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50% of the total coal production. According to EP statistics, in 2012 Viet Nam consumed 14.9Mtoe of coal (which was 0.4% of the world's total coal consumption), down 0.1Mtoe from the same period of the previous year with a reduction of 0.8%.

### **1.14 Other economies**

The coal production among APEC region is mainly concentrated in the 13 economies above. In Brunei Darussalam; Chile; Hong Kong, China; Malaysia; Papua New Guinea; the Philippines; Singapore and Chinese Taipei, , and, where coal reserves are limited and of poor quality, coal does not take a large proportion in their primary energy consumption and is mainly imported from other countries to cater to the economic development of these economies.

## 2. Investigation Report of the Project

### **2.1 Investigation Report of CNCGC Datun Co., Ltd.**

In August 2013, the project contractor carried out an investigation in CNCGC Datun Co., Ltd. , during which the contractor had intensive exchange with Director of the technical center, and chiefs in charge of the department of energy conservation, environmental protection and comprehensive utilization of resources upon the company's comprehensive utilization of coal. The contractor performed field investigation on Yaoqiao Coal Mine and Shanghai Energy Datun Power Plant, and held detailed discussion with chiefs in energy conservation and environmental protection about the current comprehensive utilization of resources and industrial chain development. The detailed investigation includes the following aspects:

#### **2.1.1 Introduction of CNCGC Datun Co., Ltd.**

CNCGC Datun Co., Ltd. was originally a large SOE invested by Shanghai under the approval the State Council in 1970 with a registered capital of RMB79,688. In 1997, it was restructured into a wholly state-owned limited liability company. In 1999, it was incorporated into China National Coal Imp. & Exp. Corporation (renamed China National Coal Group Corp in 2003). In December 1999, the company established Shanghai Datun Energy Resources Co., Ltd., which was successfully listed at Shanghai Stock Exchange in 2001.

Dadun Company is among the nation's top-1000 energy conservation program enterprises. Conveniently located on the border of Jiangsu and Shandong provinces and administratively under the jurisdiction of Jiangsu Province, the mine property covers a total area of 245 square kilometers. After four decades of development, the company has now become a large SOE that integrates coal production, pithead power generation, aluminum smelting and processing, and railway transportation. So far, it has four high-efficiency active coal mines mainly producing medium-high calorific value, low ash, low sulfur and low phosphor 1/3 coking coal, gas coal and fat coal which are high quality coking coal and steam coal, with a raw coal production capacity of around 9.1 million tons/annum; four coal preparation plants with annual raw coal washing capacity of 7.5 million tons; a coal-fired power plants and a



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the gangue-fired thermal power plant to generate power and supply heat for residents. Fly ash, slag and gangue from the power plants are used as raw material to product manufacture cement, fire retardant material and bricks. Wastes from the respective production processes become raw materials for another production process. The production processes or industrial chains make up a crisscross high-efficiency three-dimensional comprehensive utilization structure. This greatly increases the economic performance and radically improves the eco-environment.

To date, the company has invested RMB260, 685,000 on the comprehensive utilization of solid wastes. When all the projects are put into operation, the coal washing byproducts from the entire coal mine per year will supply 3,995,400t for comprehensive utilization. The 3,121,600t coal gangue, 874,100t sludge and 550,000t inferior coal produced will all be utilized. The reclamation rate of subsided land will be more than 50%, and the eco-beautification rate of subsided land will be 100%. By backfilling or reclaiming subsided land with coal gangue and fly ash, about 600 thousand m<sup>3</sup> of planting land will be restored. The greening coefficient of the mine will come up to 43%. The SO<sub>2</sub> concentration in atmosphere will reduce by 1.2%. While the environmental impact of gangue is eliminated, the landform and eco-environment of Datun Mine will be gradually restored.

### **(1) Comprehensive utilization of coal gangue**

Datun, Yaoqiao Coal Mine, Kongzhuang Coal Mine and Longdong Coal Mine Coal Preparation Plants produce average total coal gangue of approximately 1.09 million tons as one of the coal washing byproducts every year with a calorific value of 600-1000kCal/kg. To comply with the national circular economy policy, improve the environment, increase the comprehensive utilization level of coal and deal with the mass accumulation of coal gangue, middlings and sludge from the years of coal mining, Datun Company has built a coal blending center on the basis of coal gangue from coal washing processes. All the coal gangue from coal washing is supplied as fuel to the 2×440 t/h coal-fired CFB boilers furnished for the 2×135MW generating units, the 2×240 t/h CFB boilers (Units No.6 and No.7) furnished for the 2×60 MW extraction condensing turbo generator units in Shanghai Energy Datun Power Plant, the 2×15MW extraction condensing co-generating units and the 2×75 t/h coal-fired CFB boilers in the gangue-fired thermal power plant. Datun Power Plant consumes

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970,000t of the gangue from coal washing, while the gangue-fired thermal power plant consumes around 120,000t. The utilization rate is almost 100%.

In addition, the four coal mines excavate about 902,000t of mixed coal gangue every year, which the company uses for road repair, dam reinforcement and land reclamation as eco-restoration processes. The utilization rate is 100%.

### **(2) Comprehensive utilization of coal sludge and middlings**

Coal sludge is the waste from coal washing with higher calorific value than coal gangue and low ash content. The total ash content in the fired product is far lower than that in the fired product of coal gangue. Thus, it can be used as fuel for power plants. In Datun, the two low-calorific wastes of coal gangue and sludge in the coal byproduct are blended with the middlings from the mine at the coal blending center. After making sure that the fuel fed into the gangue-fired boilers is eligible and the sludge ratio is at least 60%, it is supplied to fire Units #6 and #7 and other minor co-generating CFB boilers for power generation.

At present, the four coal preparation plants produce a total of 480,000t washing sludge with a calorific value of 2500~3500kCal/kg. Besides, Datun Coal Preparation Plant and Kongzhuang Coal Preparation Plant also generate 128,000t and 88,000t of middlings, respectively, as one of the coal washing byproducts. They total 216,000t with a calorific value of 3000~3500kCal/kg. 44,700t of the sludge from the plants is used for Datun Power Plant, and 156,200t is used for Phase I of the gangue-fired power plant's sludge pipeline transmission project, mainly as the fuel required by the 2×75 t/h boilers (No.0, No.8 and No.9) furnished for the 2×15MW generating units. Eventually, all the five boilers will be fired with sludge.

### **(3) Comprehensive utilization of fly ash and slag**

The two power plants of the company produce 875,202t fly ash/slag every year, including 372,662t fly ash and 502,540t slag. Some hundreds of thousands of tons are used as clinker aggregate for cement, raw material for underground grouting, as fire retardant material or for manufacturing brick.

Datun Company makes positive effort in developing and applying solutions for the

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comprehensive utilization of fly ash. A high-pressure steam cured fly ash standard brick line project with an estimated total investment of RMB24.81 million and annual capacity (for Phase I) of 40 million bricks was put into operation in October 2007. This production line uses the surplus heat from Datun’s gangue-fired thermal power plant as the steam source, and fly ash/slag from the power plant as the main raw material. In this project, PLC remote batching control system and HF1100 automatic hydraulic variable mould-vibrated brick machine process are applied and enable 100% reuse of production waste and wastewater and zero release. The company is also planning to build an 80 million bricks/annum high-pressure steam cured fly ash standard brick line somewhere near Datun Power Plant using the fly ash from the power plant as the raw material.

**(4) Sewage (wastewater) treatment and comprehensive utilization**

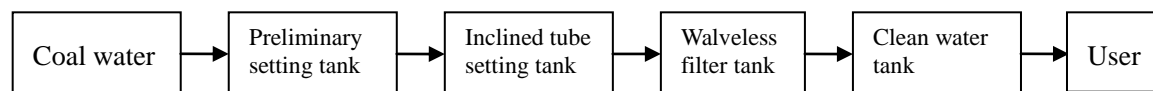
The company has implemented improvements to further increase the utilization rate of sewage/wastewater. These include purification of mine water, advanced treatment of mine water and comprehensive utilization of recycled water, totaling an aggregate investment of RMB61.17 million. Improvement facilities include 7 sewage treatment plants (including water treatment facilities and power plant industrial sewage treatment facilities) with actual sewage treatment of 40,530m<sup>3</sup>/d, 5 mine water treatment plants (including water treatment facilities and power plant makeup water treatment facilities) with actual water treatment of 49,643m<sup>3</sup>/d. All the treated domestic sewage and mine water are reused as makeup water for power plants, as sanitary water for employees of the coal mine and for watering plants.

**Table.2-1 Mine water utilization in Datun 2010**

Water yield (10000m <sup>3</sup> )	Water discharge (10000m <sup>3</sup> )	Utilization means and quantities (10000m <sup>3</sup> )						
		Total	Minin g	Coal wash	Undergroun d dust control	Domestic water	For plant s	Other uses
741.32	208.02	533.30	170.59	151.44	2.20	51.88	82.01	75.18

At present, the mine water outflow of Datun Company is 7,413,200 m<sup>3</sup>/a, of which 5,333,000 m<sup>3</sup> is used by the mine itself and 2,080,200 m<sup>3</sup> is used for agricultural

irrigation, meaning 71.94% of the mine water is used by the mine and 28.06% is used for other purposes. Table.1 shows the exact figures.



**Fig.2-2 Process of mine water treatment in Yaoqiao Wastewater treatment plant**

Central District Sewage Treatment Plant is the largest domestic sewage treatment facility of the company. It was initially built in early 1980s and expanded in late 1990s. The design treatment capacity is 15,000m<sup>3</sup>/d, but the actual capacity is 8000-10000 m<sup>3</sup>/d since world-leading 2-stage biochemical treatment processes including Pasveer oxidation ditches and surface aerators are employed. The sewage treatment rate in Central District is 100% and the treated water conforms to SL368-2006 Standards of reclaimed water quality. 4000 m<sup>3</sup>/d of the treated recycled water is directed into the gangue-fired thermal power plant where it is sterilized and used as circulation cooling makeup water for power generation. This reduces groundwater consumption by 1.2 million tons, water consumption worth RMB684,000, CODcr by 72 tons and SS by 60 tons every year. To achieve high reuse rate, economize water and mitigate environmental pollution, the company is now making advanced treatment to the treated sewage from Central district, called advanced treatment of reclaimed water, in the light of the 5-boiler 4-generator technical reform in Central District gangue-fired thermal power plant. The treated reclaimed water will be used as circulation cooling makeup water and boiler water for the gangue-fired thermal power plant and as makeup water for coal washing in Datun Coal Preparation Plant. After the project is implemented, the reuse rate of the reclaimed water in Central District will come to 100%, thus guaranteeing completely closed circulation.





**Fig.2-3 Wastewater treatment plant in Yaoqiao Coal Mine**



**Fig.24 Monitoring room of the wastewater treatment plant in Yaoqiao Coal Mine**

### **(5) Other efforts**

The company has also initiated projects to enable efficient coal mining and higher resources recovery. An example is the mine reconstruction in Kongzhuang, for which RMB440 million was inputted and which benefits from sound energy efficiency. Improvements include: (1) advanced treatment was made to the original and new underground drainage systems so that the treated mine water is used as domestic

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water for the industrial sites and the workers residential community, thus reducing the release of mine water; (2) gangue is used for comprehensive improvement in cave-in regions and eco-restoration, consuming 350,000 tons gangue every year. Not only the gangue from updated projects is made full use of, the original gangue from the coal mine is also utilized.

## **2.2 Investigation Report of Datong Coal Mine Group Co., Ltd.**

In August 2013, the project contractor carried out an investigation in Datong Coal Mine Group Co., Ltd., during which the contractor held detailed discussion with chiefs in charge of departments of energy conservation, environmental protection and Tashan Circular Economy Park about the current coal comprehensive utilization and made a site visit to Tashan Park. The investigation includes the following aspects:

### **2.2.1 Introduction of Datong Coal Mine Group**

Datong Coal Mine Group Co., Ltd. is conveniently located in the southwest of Datong, Shanxi, in the Datong Coalfield which has abundant and high-quality coal resources. Initially registered in August 1949 as Datong Mining Bureau, it is a very typical resource-based old enterprise. In July 2000, it was restructured into the present company. So far, the company has a total asset of RMB 135 billion, 73 coal mine and 800,000 employees. The mining area covers some main coal mines in north Taiyuan, with a total cumulative coalfield area of 6157km<sup>2</sup> and total coal reserve of 89.2 billion tons. Current mining operation is advanced on the Carboniferous and Jurassic formations that contain low-ash, low-sulfur, high-calorific, moderate-volatile coal of stable quality, which is a multipurpose soft coal rarely found elsewhere. In 2012, the company reported a coal output and sales of 0.17 billion tons, the 8<sup>th</sup> consecutive year to exceed a hundred million tons.

After six decades, Datong Coal Mine has now become a cross-regional, cross-industry, cross-ownership, transnational ultra large comprehensive energy group specializing in coal and covering electric power, coal chemical, metallurgy, machinery manufacturing, building material, logistics, trade, culture and tourism. The ongoing North Shanxi Coal Base is one of the 14 large-scaled coal bases listed in the national plan.

### **2.2.2 Comprehensive utilization of coal**

The past few years have witnessed prominent achievements of the Group in developing circular economy and boosting energy efficiency and emission reduction. Tashan Circular Economy Park, which was officially established in August 2009, boasts the first circular economy park among its peers with the most complete industrial chain. Embarked with a total investment of RMB 20.4 billion, it constructed

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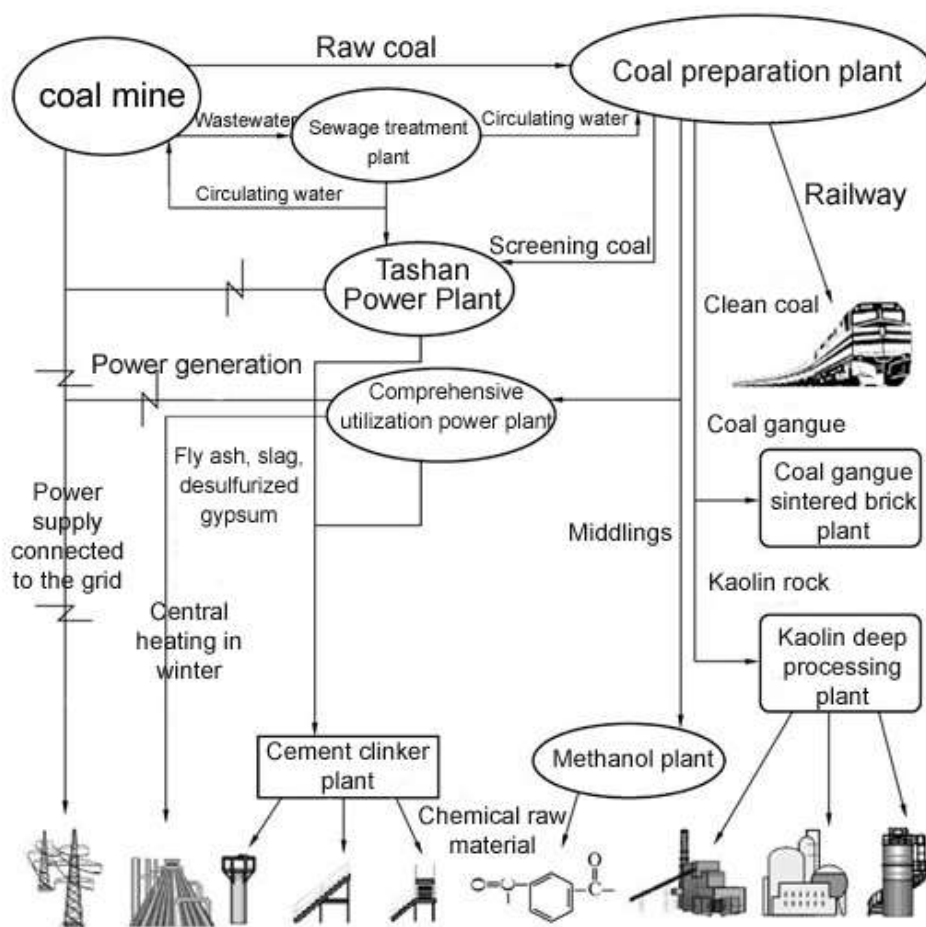
a 15,000,000t Tashan Coal Mine, a 10,000,000t Tongxin Coal Mine, a coal preparation plant, a pithead power plant, a resources comprehensive utilization power plant, a methanol plant, a coal gangue brick plant, a kaolin processing plant, a cement plant, a 4000m<sup>3</sup>/d sewage treatment plant and an exclusive railway line, called a “2-mine 10-plant 1-road” framework. All these projects are interconnected into a close-circuit material circulation cycle where waste from the previous link is right the raw material for the next link, making up the coal-power-construction material and coal-chemical complete industrial chains.



**Fig. 2-5 Tashan Circular Economy Park**

Comprehensive utilization of coal in the Park is achieved at three levels:

1) Washing and separation. All the raw coal from the coal mines is washed and separated in Tashan Coal Preparation Plant. Part of the raw coal is screened and then supplied to Tashan Power Plant. Clean coal from the coal preparation plant is delivered to external users via the exclusive Tashan railway line. Sludge, middlings, coal gangue and kaolin rock are digested in the next process.



**Fig.2-6 Industrial chain of Tashan Circular Economy Park**

2) Extension of the industrial chain to increase added value. The  $2 \times 600000$  kW Tashan Pithead Power Plant is a hub linking the upstream and downstream industrial chains in Tashan Park as well as the largest single complementary package with the largest investment in the Park. Electricity-generating raw coal is delivered directly from the coal mines to the power plant via a 1.5 km coal conveyor gallery, thus eliminating the intermediate process and preventing environmental pollution caused by dust during coal conveyance. Low-calorific middlings from the coal washing plant is supplied as fuel to the downstream comprehensive resources utilization power plant and methanol facility to achieve comprehensive utilization.

3) Substantial utilization of wastes from previous processes. Kaolin rock is delivered to the kaolin processing plant while coal gangue from coal washing/preparation processes is reused as fuel or raw material for the comprehensive utilization power plant, methanol plant and coal gangue sintered brick plant. Fly ash, slag and desulfurized gypsum from the power plant and methanol plant are reused as clinkers

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for producing cement. Domestic sewage and industrial wastewater from the Park are directed into the sewage treatment plant where they are treated and reused for other purposes. Almost none of the wastewater in the Park is released.

The construction pattern of Tashan Industrial Park is a transform to the traditional economy growth model of high-consumption, high-waste, high-pollution, and reflects the requirement of reduction, reuse, and recycle. By extending the industrial chain and draining wastes, a closed industrial chain is produced. While sustaining economic development, the cost paid by environment and resources is minimized, thus achieving low-consumption, low-emission, and high-efficiency utilization of coal resources.

In 2011, the Park reported a product value of RMB23.2 billion and also brought about great improvement in the environmental quality of the mine area. The sewage treatment rate reached 100%. The innocuous treatment rate of domestic rubbish was 100%. Good weather days above grade 2 in the mine area went up to 341. Extensive wide-coverage all-dimensional resources greening and refuse dump remediation has been implemented in the mine area. Most importantly, we have accumulated 280km<sup>2</sup> of forestry carbon sink resources covering 3 district-level cities and 11 counties, boasting the largest self-run pit prop wood base in China with an ecological value of more than RMB6 billion, which is a great contribution to the improvement of the regional eco-environment.

In terms of the social benefit, construction of Tashan Industrial Park has set an example for the transform of resource-based enterprises and made contribution to expanding coal businesses and achieving scale operation, to adjusting the industrial structure and performing diversified operation, to guaranteeing production continuity and enabling social stability of the mine area, to conserving resources and protecting environment, and to building a resources-saving and environment-friendly society.

### **(1) Tashan Power Plant**

The 2×600000kW Tashan Pithead Power Plant is a facility boasting the largest per unit capacity among its domestic peers. It is a hub linking the upstream and downstream industrial chains in Tashan Park as well as a single complementary

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package with the largest investment inside the Park. All the power-generating raw coal is delivered directly from the coal mines to the power plant via a 1.5km long coal conveyor gallery. This eliminates the intermediate transport processes and saves around RMB100 million of transportation cost as compared with its neighboring counterparts, and also prevents environmental pollution caused by dust produced during coal conveyance.

If the 15 million tons of raw coal produced by Tashan Coal Mine were delivered to power plants in the coastal region in Southeast China as is the traditional practice, the transport cost over a distance of 2300km would be more than RMB2.6 billion, and over 5 million tons of fly ash would be produced if all of the coal were used up for generating power. For Tashan Park, coal delivery is replaced by power delivery. Resources are converted locally, thus saving mass transport resources, energy resources and economic cost.

In the power plant, 2×600MW subcritical coal-fired air-cooled generating units are installed, which consume 70% less water than their water-cooled counterparts, saving 34000t of water resources every day. 5-field high-efficiency hydrostatic precipitators provides a dust removal rate of as high as 99.85%, which is an average of 0.85% higher than their domestic counterparts, reducing dust emission by 127.13 million tons every year. Limestone-gypsum wet FGD systems inputted at the same time provide a desulfurization rate of over 95%, which is 5% higher than the national standard, reducing SO<sub>2</sub> emission by 3.15 million tons every year.

### **(2) Comprehensive utilization of coal gangue and middlings**

Middlings and sludge from coal gangue and raw coal produced during coal mining after they are washed may both be used as raw materials for the comprehensive resources utilization power plant. This 450MW power plant (Datang Thermal Power Co., Ltd.) utilizes the middlings and gangues from the coal preparation plant, through co-generating process, replaces the 240 separate coal-fired boilers and supply central heating for 5,500,000m<sup>3</sup>, consuming more than 1.4 million tons of middlings and coal gangue and reduce the emission of 4000t of SO<sub>2</sub> and 6900t of flue gas every year. The environment of the mine area has been greatly improved.



**Fig.2-7 Tashan Power Generation Co., Ltd.**

The other part of the coal gangue is delivered to the 240 million bricks/a (120 million bricks/a at the first phase project) coal gangue sintered brick plant where they are crushed and sintered into standard coal gangue bricks or perforated bricks as material for major building structure and wall. This brick plant consumes 800,000t of coal gangue every year. This project was commenced in June 2008 and put into operation in June 2009 with a total investment of RMB180 million.



**Fig.2-8 Tashan Power Co., Ltd.**

Some of the middlings from the coal preparation plant is also used for the 1.2 million tons methanol facility in the Park, the first phase of which is expected to produce 0.6



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million tons methanol per year. With a total investment of RMB3.6 billion, it is the largest ongoing coal chemical project in Shanxi province. Applying the world-leading technique from Shell, it is also one of the largest methanol facilities by unit capacity in the world. The largest Shell gasifier in ongoing projects across the world is used in this project and has a capacity to produce 1.6 billion m<sup>3</sup> of synthesis gas per year. When complete, it is expected to consume 0.8 million tons raw material coal, and bring in annual sales revenue of RMB1.45 billion and a profit of RMB0.35 billion.

### **(3) Processing and utilization of kaolin**

Tashan Mine is rich in kaolin reserves with excellent quality. To make effective use of this coal-series concomitant, Datong Coal Mine Group invested and constructed a Tashan Kaolin Chemical Plant. With a design capacity of 50000t ultrafine calcined kaolin per year, the plant is able to consume 100,000t of kaolin rock from the coal mines. The project was commenced in April 2008 and complete in June 2009. Using up-draught rotary kilns and calcining processes, the plant produces 6250mesh and 4000mesh calcined kaolin powder, with the 6250mesh kaolin being the finest in the world. These products are widely used in paint, ceramics, papermaking, coating and cosmetics, 90% of which is sold to overseas markets like Canada and Australia.

The plant also uses energy-saving hot-blast stoves furnished with surplus heat recovery devices that provide 35% higher heat efficiency than common heat exchangers, consuming 4300t standard coal every year.

### **(4) Comprehensive utilization of fly ash**

Fly ash, slag and desulfurized gypsum from the power plant and methanol plant are used on the cement clinker line. The first phase of this project is a 4500t/d production line that consumes 53,000t of the fly ash, slag and desulfurized gypsum. The product is used as substitutive raw material and mixed material for producing cement, producing 2.4 million tons of high-quality, low-alkali, high-grade cement every year. Allowance is made for a production line of the same capacity in the second phase. The eventual capacity will be 10000t/d cement clinker.

Accompanying the cement clinker line will be a pure low-temperature surplus-heat power generation system that is expected to supply around 30% of the power load for

this production line, reducing the production cost of clinker by RMB10~15/t, and at the same time limiting the heat pollution and dust pollution of the cement plant on the surrounding environment.

#### **(5) Circular utilization of water resources**

Inside Tashan Park, after the precipitation treatment, the majority of the mine water is supplied to the power plant and other users as makeup water for the production in the Park. A sewage treatment plant with design daily capacity of 4000m<sup>3</sup> has already been installed in the Park. The recycled water from this facility, when used as the water source for Tashan Power Plant, will fully accommodate 21000t/d of water consumption of the power plant. The remaining mine water will be used as domestic, fire control and underground dampening of the mine area after receiving advanced treatment.

When main construction of coal preparation plant was ongoing, coal-washing water reuse and close-circuit circulation systems were installed synchronously in line with the EIA requirements. Sludge water from coal preparation and wastewater from the plant are all directed into the two 45m-diameter high-efficiency thickeners for precipitation treatment. The overflow is returned into the main powerhouse as circulating water while the underflow is directed into the press workshop to recovery sludge before the filtrate is further polished into renewed clear water.

All sewage from the power plant is treated in the sewage treatment plant and reused in circulation. Clean water after treatment may also be supplied to residents for domestic purposes. Wastewater from the chemical plant is also involved in the cyclic utilization of wastewater through the sewage treatment plant. Besides, steam from the chemical plant is condensed and cleaned before it is reused as pure water.

## **2.3 Investigation Report of China Pingmei Shenma Group**

In September 2013, the project contractor carried out an investigation in China Pingmei Shenma Group, during which the project contractor held detailed discussion with chiefs of the departments of energy conservation and environmental protection of Pingmei Shenma Group about the current comprehensive utilization of resources and made a site visit to its comprehensive utilization power plants in No.4 Coal Mine. The investigation includes the following aspects:

### **2.3.1 Introduction of China Pingmei Shenma Group**

China Pingmei Shenma Group (China Pingmei Shenma Energy & Chemical Group Co., Ltd.) is an ultra large state-owned business group specializing in energy and chemical. Founded in December 5, 2008 by joint reorganization of two China top 500 enterprises in Henan Province– Pingmei Group and Shenma Group, the company boasts a total asset of over RMB80 billion, making it one of the largest industrial enterprises in the province.

The original Pingmei Group was located in the center of Henan Province, where it owned the first ultra large coal base independently explored and designed by China. With a host of charred coal, fat coal and lean coal, it is a coking coal and thermal coal production base in China with all coal species well known as a coal store in the Central Plains. Now the group has already shaped a 1-headquarter 2-flank layout in Henan Province. It is headquartered in Pingdingshan coalfield and has Ruzhou coalfield and Yuzhou coalfield at its sides. The coal mining area is endowed with rich coal resources. The three coalfields, together, cover a coal-bearing area of nearly 3000 square kilometers with geological coal reserve of 15.4 billion tons. Now it has 31 production wells capable of producing 70 million tons of coal. At present, the group is actively integrating coal resources within the province and in the northwestern part of China, and making even greater efforts in developing resources in Binchang mining area in Shaanxi, and Xinjiang and Inner Mongolia. As projected, its raw coal output will exceed 80 million tons by the end of the 12<sup>th</sup> five-year plan period. The original Shenma Group was an almost 30-year-old chemical enterprise that had gained better experience both in product manufacturing and pollutant remediation, and owned a lot of advanced techniques. Its nylon 66 salt capacity ranked the first in Asia and the

fourth in the world. Its nylon 66 engineering plastic capacity was the No.1 in China. Its nylon chemical product base ranked the 4<sup>th</sup> in the world and the first in Asia.

Relying on the physical advantage and rich coal and rock salt resources in Pingdingshan, by implementing the coal-based diversification strategy, Pingmei Shenma Group has preliminarily established a 4+5 industrial system consisting of the 4 pillar industries of coal mining and preparation, nylon chemical, coal-coke chemical and coal-salt chemical, and 5 ancillary industries of electric power, modern logistics, high and new technology, building engineering and building materials, and electromechanical equipment. It is now a cross-regional, cross-industry, cross-ownership and transnational large modern energy chemical group.

### **2.3.2 Comprehensive utilization of coal**

The original Pingmei Group started to try comprehensive utilization of coal gangue, coal slime, fly ash and coalbed gas as early as in the late 1970s, having accumulated valuable experience in this respect. As resources reorganization and circular economy push on, Pingmei Shenma Group is already taking comprehensive utilization as the key to circular economy, expanding its field of comprehensive utilization with the time. Now it has formed three circular economic main industrial chains braced by coal development and utilization:

1) Coal-power-building industrial chain. This is a coal-power, heat-building material industrial chain in which coal gangue and coal slime is used as the source. Coal gangue, coal slime and faulty coal are used as low-heat fuel to generate power, coal mine methane is used to generate power or fire boilers, the surplus heat from the power plants is used to supply heat, the coal gangue is used to produce brick, and fly ash is used to produce cement or masonry block.

So far, Pingmei Group has 6 built and ongoing comprehensive utilization power plants totaling installed capacity of 1150MW and processing 2.4 million tons of faulty coal, coal gangue and coal slime. It has built 7 coal gangue brick plants capable of producing 320 million bricks a year and 2 coal ash concrete block plants capable of producing 500,000m<sup>3</sup> a year. The group follows the principle of gas drainage before

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coal mining, mining accompanied by gas drainage, and drainage and utilization are of equal importance, and has also built 49 gas drainage stations that drain up to 64 million m<sup>3</sup> of CMM a year and 4 gas power stations. The CMM drainage and utilization rate increases year by year. These projects make the best use of coal gangue, coal slime, fly ash and CMM, which not only add to the profit of the company, but also reduce environmental pollution in the mine area.

2) Coal-coke-chemical industrial chain. This is a coal-coking-tar processing industrial chain starting from coal coking in which coal is prepared before the clean coal is delivered to the coking plant, Crude benzene, ammonium sulphate and coal tar associated with the coking process is processed into chemical products. So far, chemical products produced through this industrial chain include the main coking product coke, which is further processed into carbon black, carbon, industrial naphthalene and asphalt, and crude benzene is further refined into fine benzene, ammonium sulphate and graphite electrode.



**Fig.2-9 7.63m coking furnace of Shoushan Coking and Chemical Company of Pingmei Shenma Group**

3) Coal-gas-chemical industrial chain. In this chain, at present, the great deal of surplus coke oven gas from the coking process is used as the source from which hydrogen is extracted. Part of the hydrogen so produced is delivered to the benzene refining plant where crude benzene is hydrogenated and distilled to produce benzene, toluene and xylene for sell, part of it is made into polycrystalline silicon by silanization, and part of it is delivered to the nylon chemical company to produce

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cyclohexanol by hydrogenation. The cyclohexanol so produced is then further processed into adipic acid, which is reacted with hexane diamine into nylon 66 salt that is raw material for engineering plastic and cord fabric. The byproduct from coal gas hydrogen extraction, desorbed gas, is delivered to the methanol plant for produce methanol before it is synthesized into methyl ether for sell, and the purge gas from methanol production is either used for power generation at the power plants or for baking ultrahigh-power graphite electrode. Through hydrogen and fine benzene, the group successfully realized an industrial chaining from coal chemical to nylon chemical. For the wastewater from the production, after treated at the sewage plant, part of it is used for production cooling and part of it is used to water plants.

Besides, the carbon black produced out of the tar by Tianhong Coking Company, an affiliate to the group, can be provided to China Shenma Group Rubber Tyre Co., Ltd. to produce tires, thus forming a coal-coking-tar-carbon black-rubber tire industrial chain. The new industrial chains not only enable the maximal resources utilization of the group and transform its original development pattern, but also increase the added value of its products. Through resource sharing and industrial chaining, Pingma and Shenma are truly combined into a large coal chemical enterprise of coal deep processing from energy mining and raw material processing.

### **(1) Comprehensive utilization of coal gangue**

In the past, the coal products process was raw coal – washing – coal product loading and delivery, and coal gangue was removed to the dump site. The group has now 20.69 million tons of coal gangue dumped in the mining area. As the mine is closely adjacent to the downtown area, the coal gangue makes some pollution to the surrounding environment. To protect the environment and make the best value of the coal preparation byproducts, the group has assigned the operation of coal byproducts to its affiliate (Tianhao Industries Company). It forms a circular product line of a raw coal – washing – product delivery and byproduct – byproduct terminal of Tianhao Company – processing and blending – finished product (byproduct) loading and delivery line. In addition to improving the environment and reducing land occupation, this also saves a large sum of money for the group.

The coal gangue, coal slime and other associated products delivered out of the mine

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are used to generate power, supply heat, produce brick, ceramic and cement, build roads and repair caving areas. The group has 6 built and ongoing comprehensive utilization power plants totaling installed capacity of 1105MW. These plants use coal gangue, coal slime and other low-heat fuels to generate power, or supply heat to the mine area by cogeneration, processing about 2.4 million tons of coal gangue, coal slime and middlings a year. Coal gangue is also used to produce gangue fired hollow brick. Now the group has 7 coal gangue brick plants capable of producing 520 million bricks and consuming about 1.56 million tons of coal gangue a year. Coal gangue is also used to fill mined areas and for land reclamation, having greened 22 gangue hills, filled more than 10 million tons of subgrade and reclaimed about 7.3 km<sup>2</sup> of land. This minimizes land occupation of coal gangue piles and eliminates environmental pollution.

### **(2) Comprehensive utilization of CMM/VAM**

The group endeavors to boost the comprehensive utilization of CBM/CMM. To ensure gas drainage before coal mining, utilization of the drained CMM, 14 active mines have started CMM drainage. Now 49 drainage pump stations, including 11 surface stations and 38 underground stations, have been built and equipped with 102 drainage pumps with installed power of 17,427kW and main drainage pipeline of 79,546m.



**Fig.2-10 CMM power plant in No.4 Coal Mine of Pingmei Shenma Group**

To minimize atmospheric pollution caused by CMM from coal mining, make the best

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use of the non-renewable resources, facilitate gas drainage by utilizing CMM and guarantee work safety in the wells, the group made great effort and in succession built four 4×500kW low-concentration gas power plants in the No.4, No.8, No.10 and No.12 coal mines, which generate power using the CMM drained from the coal mining process with the methane concentration of 6%~30%. So far, all these gas power stations are running satisfactorily and produce more than 30 million kWh of power every year.

Since a gas utilization trial was started in the No.10 coal mine in 2003, now the group has built a 5000m<sup>3</sup> gas holder which uses the around 30% concentration gas drained from underground as the fuel gas for the employee dining rooms of the mining wells. This utilizes 800,000m<sup>3</sup> of CMM (net) every year.

Besides, in 2009, the group, in cooperation with Shengli Oil Field Shengli Power Machinery Group Co., Ltd., introduced a VAM oxidation system in the No.4<sup>th</sup> coal mine to facilitate the VAM utilization. With a processing capacity of 60,000m<sup>3</sup>/h, this system decomposes and oxidizes VAM with the methane concentration of 0.2~0.6% from the shaft under high temperature. By 2015, the group also plans to introduce 10 such systems to the northern air shaft in the No.4 and No.8 coal mine, the horizontal air shaft No.3 in the No.10 coal mine, the Ji-4 air shaft and the northern air shaft in No.12 coal mine. As estimated, in 2015, the annual VAM utilization volume will be 40 million m<sup>3</sup>, and 525,000 tons carbon dioxide will be reduced.



**Fig.2-11 VAM oxidation project in No.4 Coal Mine**

### **(3) Comprehensive utilization of fly ash**



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To radically solve ash discharge from power plants and guarantee the production and sustainability of the power plants, the group has used fly ash from the power plant to produce new types of building material such as cement and concrete block, and built 2 fly ash concrete block plants boasting the largest dry method cement clinker production lines, capable of producing 3.1 million tons of cement clinker and 500,000m<sup>3</sup> fly ash concrete block, consuming 700,000 tons of fly ashes from the power plants. This provides both economic benefit and social benefit. Some of the fly ash is also used as fill material underground and for grouting underground to extinguish fire of coal mines.

### **(4) Comprehensive utilization of sewage**

To solve the tailing water treatment, environmental pollution and water insufficiency of the mining area, the group initiated tailing water reconstruction projects so that tailing water is locally treated and reused in circulation. Now tailing water is widely used for coal mining, coal preparation, power generation, domestic purposes and agricultural irrigation. For the 21 coal production units across the mine area, there are 16 large comprehensive utilization water plants that treat over 38 million tons of tailing water. The utilization rate is over 80%. This minimizes pollution, alleviates the water insufficiency and achieves zero emission of sewage.

The sewage discharge system of the power plants is a three-part system consisting of a domestic treatment system, an industrial wastewater system and a storm-water system. Industrial wastewater includes effluents from the domestic sewage treatment, flushing water from oily workplaces and oily storm-water from the transformer area. This water is directed into the pipe mixed chemical feeder before coming into an inclined plate settler where it is deprived of oil by a pneumatic flotation machine, directed into a valveless filter and then back into the reuse water tank for reserve. All the water is reused for planting and slag pouring in the plant when it reaches the national grade 1 discharge standard.

The nylon chemical company has built 15 new sewage treatment tanks which not only raise the capacity of the sewage treatment plant from 250t/h to 400t/h, but the treated water, which used to conform to the national grade 1 discharge standard, is also directly used as makeup water for production circulating water of the company.

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Production wastewater generally achieves zero discharge.

## **2.4 Investigation Report of Jincheng Anthracite Mining Group**

In August 2013, the project contractor carried out an investigation in Jincheng Anthracite Mining Group, during which the contractor held detailed discussion with chiefs from the departments in energy conservation, environmental protection and Coal-bed Methane Industrial Bureau about the current comprehensive utilization of coal and made a site visit to Jincheng 120MW CMM Power Plant. The investigation includes the following aspects:

### **2.4.1 Introduction of Jincheng Anthracite Mining Group**

Shanxi Jincheng Anthracite Mining Group Co., Ltd. is a limited liability company held by Shanxi State-Owned Assets Supervision and Administration Commission (holding 60.31%), and participated by three shareholders of China Development Bank (holding 19.63%), China Cinda Asset Management Corporation (holding 16.45%) and China Construction Bank (holding 3.61%). As the major manufacturer of quality anthracite, the largest CBM extraction and utilization enterprise, and the largest methane power generation enterprise group in China, it governs 55 subsidiaries and 10 branches. As of the end of 2012, the total asset of the enterprise is RMB185.6 Billion. The business revenue in 2012 reached up to RMB168.4 Billion.

In recent years, Jincheng Anthracite Mining Group, guided by the scientific outlook of development and following the medium and long term development strategy of constructing environmental and green mine by coal, gas and electricity comprehensive development, has formed a modern industrial pattern with circular, green and safe development and supported by six industries of coal, coal chemical industry, CBM, electricity, coal machine manufacture and emerging industry, which promoted the rapid growth of economic scale and benefits for the enterprise. At present, the enterprise possesses 10 active coal mines with annual coal output capacity of 53.9 million tons. 21 coal chemical companies with total ammonia capacity of 15 million tons, urea capacity of 12 million tons, other fertilizer capacity of 6.35 million tons, methyl alcohol capacity of 4 million tons, fine chemicals capacity of 1.1 million tons and oil products capacity of 100,000t in 2012. 4420 CBM surface drainage wells, which form five CBM drainage bases of Jincheng, Taiyuan, Lvliang, Jinzhong and Changzhi with daily CMM production capacity of 4

million m<sup>3</sup> and surface drainage volume and utilization volume accounting for above 60% of that in China and ranking first for five consecutive years. It has constructed the 120MW CMM power generation plant which is the largest in the world with 97 sets of gas generator units, and formed the integrated industrial chain of CBM/CMM exploration, drainage, delivery, compaction, liquefaction, chemical industry, power generation, gas vehicle and natural gas for citizens.

#### **2.4.2 Comprehensive utilization of coal**

Jincheng Anthracite Mining Group firstly developed CBM exploitation test as early as 1993, and coal resource comprehensive unitization has been taking the lead in China. Currently, Jincheng Anthracite Mining Group is, according to the idea of coal-based pluralistic development, strengthening the industrial chain construction of coal-gas-chemical, coal-coking-chemical and coal-gas-electricity, and constructing an interactive development mechanism with advantage mutual complementation, grafting, and magnifying, which improves the internal conversion rate of coal resources, expands the profit space of coal resources and realize the interactive development of coal, chemical and power industries.

The first is to follow the coal-gas-chemical integrated development path closely, focus on promoting fertilizer production stabilization and chemical expansion project, and accelerate the construction of sulfur coal clean unitization and circular economy chemical industrial park and other 64 coal chemical technology transformation projects along the direction of high-end, poly-generation, circular and modern coal chemical industrial park construction. The sulfur coal clean unitization and circular economy chemical industrial park uses the fault coal and coal mine gas with high sulfur content, dusty and high ash fusion point as the raw material which is reserved abundantly in Jincheng mining zone but has not separate mining and direct utilization value, and constructs the project of clean fuel made by methyl alcohol and coal ash and slag comprehensive used building materials relying on the existing technology for pulverized coal gasification under pressure in Hangtian gasifier and MTG technology. The high-sulfur anthracite clean utilization 100,000t/a synthetic oil demonstration project uses the No.15 lambskin and adopts the core gasification technology, which is the ash fluidized bed pulverized coal gasification technology with own intellectual

property right to produce quality No.93 gasoline mainly and byproducts of refined methyl alcohol, dimethyl ether, ethylene and propylene.

The second is to enhance the development and utilization of coal associated resources such as CBM, as well as coal slime and coal gangue, and construct the coal-gas-electricity industrial chain. The enterprise, relying on the coal and CBM resource advantages, actively develops CBM/CMM electricity generation, coal slime and coal gangue pithead generation projects which are energy saving, environmental and with good benefits. The enterprise has constructed 5 power plants which are in operation with total installed capacity of 189MW. On that basis, the group also actively plans to construct the integrated gasification combined cycle pithead power generation plants which have high efficiency and low emission. Compared with common coal-fired power plant, the plant has the superiorities of high power generation rate (about 45%), high pollutant removal efficiency (98%) and small water consumption. After being completed, the project will further promote the green and efficient development of the coal-gas-electricity industrial chain.

In the mean time, Jincheng Anthracite Mining Group has successfully mandated Taiyuan Coal Gasification (Group) Co., Ltd., and obtained the coal resource control right of Sanjiao No.1 Coal Mine by implementing joint venture and cooperation, which lay firm foundation for relying on coking coal resources, developing coking industry and constructing “coal-coking-chemical” circulated industrial chain.

### **(1) Comprehensive utilization of CBM/CMM**

Jincheng Anthracite Mining Group has nearly 20 years of exploration, innovation and practice in the aspect of CBM/CMM development and utilization. During the long-term practices of gas prevention and control, it has gradually fishes out a successful mode of combining surface underground drainage with surface drainage in advance, and combining gas drainage and utilization with the promoting of utilization. The CBM/CMM drainage and utilization volume increases ceaselessly. In 2011, the CBM/CMM drainage volume of Jincheng Anthracite Mining Group reached 2.042 billion m<sup>3</sup>, and the utilization volume reached 1.346 billion m<sup>3</sup>, equal to reducing 20.19 million tons CO<sub>2</sub> emission and amounting to 1.6421 million tons standard coal. It has successfully developed and mastered the drilling process and technology of

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surface vertical well, ground cluster well, and multilateral horizontal well, which own intellectual property right and are suitable for various geological conditions, formed the largest surface CBM well groups in China and 189MW CMM power generation gross installed capacity, constructed 4420 surface wells, the world biggest CMM power plant and the largest-scale CBM compression station in China with daily production of 1 million m<sup>3</sup> /d, formed an integrated industrial chain of CBM/CMM exploration, drainage, delivery, compaction, liquefaction, chemical industry, power generation, auto fuel and natural gas for citizens, and completed CBM supply pipeline network with total length of 172km. Every day about 1.4 million m<sup>3</sup> CNG and 1.2 million m<sup>3</sup> LNG are delivered continuously to over 20 cities nearby and southeastern coastal areas to improve the living environment of city and improve the life quality of citizens.



**Fig.2-12 CBM surface development in Jincheng Anthracite Mining Group**

The CBM/CMM utilization methods of Jincheng Anthracite Mining Group contain:

(1) The low-concentration CMM drained underground with concentration of 16%-30% is mainly used in power generation. The 120MW CMM power plant has been constructed and formally put into operation since 2009, which is one of the first CBM projects with the Clean Development Mechanism approved by NDRC. It, as a standard energy saving and emission reduction project, uses 180 million m<sup>3</sup> of CBM and generates 720 million kWh electricity annually, equal to 2.7 million tons of CO<sub>2</sub> emission reduction and amounting to 219,500t standard coal. The fuels consumed in the power plant are the CMM drained from Sihe mine. The plant is arranged into four

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units, and each unit is equipped with 15 Caterpillar G3520C gas turbine generator sets with generated power of 1800KW for each set. Meanwhile, the tail gas of the engine will be collected and exchanged through 3 sets of 6t/h waste heat boilers to drive one set of 3000KW gas turbine generator set to generate power. The gas and steam power circular generation is realized. The jacket cooling water of the generator set can be used in concentrated heating in this plant and Sihe mining area after heat exchange so as to realize united circular production and resource comprehensive utilization. The electricity generated by the plant will fully connect to the grid via step-up substation.



**Fig.2-13 Sihe 120MW CMM power plant**

(2) The CBM drained from surface well with methane concentration of above 98% will be for civil use and industrial purposes. There are mainly three ways: the first one is to use as civil gas, vehicle and industrial fuels by compression (CNG) via tank car and pipeline delivery, which radiation radius can reach 300km covering the entire province and nearby areas. The second one is to use as civil gas, auto and industrial fuels by liquefaction (LNG) via tank car, which radiation radius can reach 2000km covering the Yangtze River Delta and Pearl River Delta areas. The third one is to enter the national west-east natural gas transmission pipeline. It has constructed the coal-bed methane delivery pipeline network with total length of 172km.

At present, CBM/CMM for civil use has covered Jincheng, Changzhi and Jinzhong with 150,000 households and 400,000 people. For vehicle fuels, 21 CBM stations have been constructed in Jincheng, Changzhi, Taiyuan, Linfen and Henan Jiaozuo

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with over 300 special tank cars for CBM transportation. Only in Jincheng, the number of automobiles using CBM as the fuel is 13800, and the total number of buses and taxis in Taiyuan using the clean fuel is 5700.



**Fig.2-14 CNG tank car in Jincheng**



**Fig.2-15 CBM filling station in Jincheng**

In 2009, CBM liquefaction project Phase 1 of Shanxi Towngas China Coal-bed Methane Company Limited, the largest CBM liquefaction project in China, was put into operation. It is the coal-bed methane liquefaction project developed by Shanxi Towngas China Coal-bed Methane Company Limited which is jointly contributed by Jincheng Anthracite Mining Group and Hong Kong and China Gas Company Limited.



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It adopts the international advanced MRC mixed cooling technology to cool the CBM to  $-162^{\circ}\text{C}$  and covered to liquid under normal pressure for storage and transportation, which becomes safe and convenient energy products. The total investment of this project is 98 million USD, and the designed production capacity is 0.9 million  $\text{m}^3/\text{a}$ .

(3) The group is actively researching the underground VAM utilization, and is working on the planning of the VAM and low quality CMM comprehensive utilization projects for each coal mine. The investigation and calculation on the methane concentration and total amount of VAM in each coal mine has been done and the compiling of the feasibility studies has been finished.

### **(2) Comprehensive utilization of coal gangue and fly ash**

Jincheng Anthracite Mining Group uses coal gangue and fly ash comprehensively in two aspects: one is to use the large amount of coal slime and gangue generated during coal production as well as power plant fly ash to greatly develop the building material projects. It has constructed and operated the coal gangue brickyard with annual production of 65 million standard bricks in Fenghuang mountain mine. The coal gangue brickyard in Zhaozhuang mine with annual production of  $4 \times 65$  million standard bricks, which is under construction, uses the fly ashes generated by coal and gangue firing in power plant as raw materials to make coal gangue vitrified bricks, cement blocks and cements. The phase I project ( $2 \times 65$  million standard bricks) was put into operation in the end of 2007. The two brickyards can consume 500,000t coal gangues each year, and reduce stock yards by 140000  $\text{m}^2$  and clay brick clay taking lands by 66,700  $\text{m}^2$ . Meanwhile, by the coal gangue filling reclamation technology it has accumulatively made nearly 1 million  $\text{m}^2$  of lands and reclaimed about 58  $\text{km}^2$  of lands.

The second one is to use coal slime and gangue to generate power. With the development of main coal business of the enterprise, the mine coal preparation plants constructed at the same time generate large amount of byproducts such as coal slimes and gangues. Therefore, the group is actively planning to construct large-capacity pithead power plant. At present, the phase I of 50,000kW coal slime and gangue comprehensive utilization power plant in Chengzhuang mine has been constructed,

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which firstly adopts the boilers firing the mixed anthracite slime and gangues, and firstly fired the coal slime and gangues by proportion of 8 : 2. It is of significant meaning for demonstration. The first phase  $2 \times 600,000\text{kW}$  project of  $4 \times 600,000\text{kW}$  pithead plant in Zhaozhuang mine adopts air cooling turbines to generate power by using smalls, coal slimes, middlings and gangues.

The group also actively promotes the  $2 \times 135\text{MW}$  coal gangue comprehensive utilization cogeneration project jointly established with Shanxi Yangcheng County Thermal Power Co., Ltd. and Yangcheng County Urban Collective Industry United Society. This project covers  $167,000 \text{ m}^2$  with total investment of RMB1.45 billion. The power generated in the plant will directly connect to the grid and the heat will directly connect to the heating supply network of Yangcheng County. This project has realized single set test run in 2012. It is expected that after putting into operation, the project can not only consume 1.29 million tons of low-heat value fuels such as coal slime and gangues, generate 1.5 billion kwh of electricity, and realize added industrial value of 130 million Yuan, but also can realize the centralized heating area of 3.5 million  $\text{m}^2$ . It is an energy saving and environmental protection comprehensive utilization project. It can substitute 105 nearby scattered small boilers, save over 60,000t of raw materials annually and reduce 25,000t of slag, dust and sulfur dioxide emission.



**Fig.2-16 Yangcheng 2x135Mw coal gangue comprehensive utilization cogeneration project**

**(3) Comprehensive utilization of water resources**

Jincheng Anthracite Mining Group insists on the policy of resourcezation of wastewater and recovers and recycles the mining water, industrial waste water and domestic sewage. At present, the enterprise has totally constructed 13 mining water processing plants with designed processing capacity of 100,000m<sup>3</sup>/day. The effluent quality reaches the primary standard of sewage comprehensive discharge in China. After being processed, the mining water is used in power plant, greening, coal washing, staff bathhouse, underground dust removal, landscape and ground watering. For the air cooling turbine used in Zhaozhuang 2×600,000kW pithead power plant, the designed annual water consumption is 3.72 million tons, among which 2.21 million tons is used the water discharged from the mine, accounting 60% of total water consumption.

## **2.5 Investigation Report for Coal Comprehensive Utilization in Indonesia**

In September 2013, the project contractor carried out an investigation in Indonesia, during which the contractor met with the members of the Indonesia project teams of Shenhua Group and the China Geology Survey Bureau in Kuala Lumpur, held detailed discussion in coal industry situations and coal comprehensive utilization of Indonesia, and conducted investigations to the project sites in Indonesia.

### **2.5.1 General situations of Indonesian coal industry**

Indonesia is one of the APEC economies with abundant coal resources and great potential of coal industry development in the world. Its coal resource reserve is 58 Billion Tons, among which 19.3 Billion Tons has been proved, and 5.4 Billion Tons is the recoverable reserve for commercial development. The coal resources of Indonesia are mainly distributed in South Sumatra islands (39%), East Kalimantan (30%), South Kalimantan (13%) and other places (West Java Island, Sulawesi Island, and West Irian Island) (18%). For coal properties, the anthracite accounts for 0.36% of total reserve, bituminous coal accounts for 14.38%, sub-bituminous coal accounts for 26.63% and brown coal accounts for 58.63%. The coal quality in Indonesia is good with features of low ash, low sulfur and high heating value. Besides, there is vast CBM reserve in Indonesia with resource quantity of 453TCF.

At present, Indonesia is the 7<sup>th</sup> largest coal production economies in the world, and the largest coal production and consumption economies in Southeast Asia. As per the authoritative estimate of International Energy Agency (IEA), in 2009, the coal output in Indonesia is 301.5Mt, including hard coal 263.3Mt. Most of the mines in Indonesia are open-pit coal mines, with annual capacity of 2.0~10Mt. In 2009, Indonesia, as the largest steam coal exporter in the world, exported 237.2Mt coals, including 200.2Mt steam coals. About 87% of the hard coal output is used for export and the rest is sold in domestic market. The domestic coal demands are mainly from power industry, followed by cement industry, paper-making industry and metallurgic industry. The coals used in power generation account for 65% of total coal consumption.

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The coal industry of Indonesia is comprised of four kinds of entities: state-owned company (PTBA), corporate contractors (CCOW), mines of mining right owner (KP) and cooperated mines (KUD). The coal production in Indonesia is very intensive. Few large coal companies control the domestic coal production in Indonesia. Currently, the large coal companies are PT Bumi Resources, Adaro, Kideco Jaya Agung, Banpu and the state-owned coal company PTBA, which coal outputs account for 75% of total coal production in Indonesia. The top ten coal production companies of Indonesia occupy 57.19% coal export volume.

In general, the coal industry in Indonesia has prosperous development prospect due to the following favorable factors:

(1) Indonesia, in domestic energy strategy, further highlights the position of coal in national economy and energy structure. The coal production and coal domestic consumption will become of new growth point of coal industry development.

(2) The geological survey is not yet conducted overall. The unproved resource potential is vast. The Indonesian government will strengthen the survey.

(3) The laws and regulations on mines become sound increasingly. The issuance and implementation of *Indonesia's New Mining Law* are positive for regulating coal resources and coal enterprises to certain degree.

(4) The infrastructure construction is paid more attention to, which is expected to improve the coal production and transportation capacity in Indonesia.

(5) The coal utilization technology develops rapidly. For example coal liquefaction, coal gasification and lignite quality improvement all make progress with varying degrees. The industrialization of coal comprehensive utilization has become a favorable trend in Indonesia.

### **2.5.2 Coal comprehensive utilization in Indonesia**

Indonesia is still in a fledging period for coal comprehensive utilization. The problems are mainly the mismatch of technology and infrastructure, laggard management awareness, and lack of incentive system. At present, Indonesia is

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accelerating the construction of the projects for various CBM comprehensive utilization and brown coal upgrade, and developing slowly in other fields.

### (1) CBM comprehensive utilization



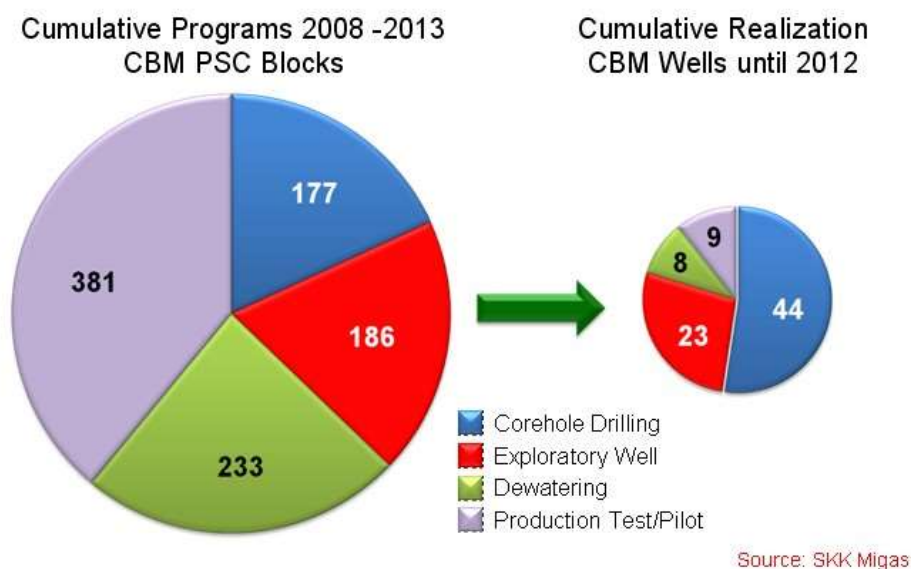
**Fig.2-17 Indonesia's three largest CBM basins**

Indonesia has the fifth largest CBM potential in the world, with resources reaching 453TCF in 11 basins. Since its development in 2008, CBM exploration has continued to expand with 39 CBM contracts awarded and more CBM areas are to be offered in 2012. According to the government's work plan, CBM production is expected to reach 500 MMSCFD in 2015, 1,000 MMSCFD in 2020, and 1,500 MMSCFD by the year 2025.

The Indonesian government has realized the potential of CBM as a resource for power generation due to its cost-effectiveness (compared to the import of oil) and environment friendly nature. Starting from 2007, the government has passed some new legislation for CBM development as part of its program to stimulate the development of unconventional resources. This legislation is aimed at providing more protection for investors and increasing CBM operators' profit sharing to 45 percent (oil and gas operators receive 15 and 30 percent respectively).

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The first significant CBM project in Indonesia was the Sanga-Sanga block in East Kalimantan that was awarded in 2009 to a consortium led by VICO, a joint venture between British giant BP and Italy's ENI. State-owned energy company Pertamina conducts the second CBM project (located in South Sumatra) in Indonesia through its subsidiary Pertamina Hulu Energi.



**Fig.2-18 Progress of CBM development in Indonesia**



**Fig.2-19 VICO CBM power generation project**

CBM in Indonesia is usually transmitted through pipelines, for export, LNG production and supply as the fuel of power plants. CBM produced in Sanga-Sanga block, operated by VICO has been supplied to the Bontang LNG facility since March



2011. Commercialization options for large scale CBM to LNG projects is under discussion.

Some gas-fired power plants also start to use CBM as the fuel. VICO has successfully supplied half One MMSCFD of CBM from 15 wells on the block to a gas-fired power plant in Sangatta, East Kalimantan in 2013. The power plant is owned by utility firm PT PLN. Construction was completed at the end of 2012. The plant is able to generate between two and four megawatts of power. The CBM-powered plant can provide electricity to around 4,000 households in the area.

### **(2) Fly ash comprehensive utilization**

Since 2006, Indonesia has invested to construct 20000MW thermal generator sets in succession, excluding the small size sets constructed in various regions. The fly ash discharged every year will at least reach 20Mt and the output increases year by year. However, the fly ash utilization rate is very low in Indonesia. About 45% fly ashes are used in land filling, 50% used for storage and only 5% used in building materials production. Compared with the high utilization rate (70% ~ 80%) in developed European and American economies, the gap is very large.

Basically no Indonesian cement and concrete manufacturer use the fly ash. The blocks used in construction engineering adopt the common clay vitrified bricks, concrete air brick and concrete perforated bricks rather than the products of aerated concrete blocks produced by fly ashes. The emerging fly ash high value utilization is not involved in the road engineering and construction engineering in Indonesia.

### **(3) Brown coal upgrade**

Over 58% coals in Indonesia are listed into the low-rank coals (brown coal) with high water content and low heating value. Because of its high water content and tendency of spontaneous combustion, the low-rank coals are unsuitable for transportation. In order to prevent from spontaneous combustion, the inert gas blanket and proper compression technology are required, while the high water content increases the transportation cost of coals. If the water content is reduced, it will cause higher oxygen content so that the heating value will be reduced. Therefore, the low-rank coals are mainly used in pithead power generation. However, the thermal efficiency is



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low and waste gas emission is large for the direct combustion of brown coal, which greatly impacts the environment. In recent years, Indonesian government has passed some guiding bills to promote low-rank coal conversion technology in domestic market. The bills stipulate that by 2014 all exported coals of Indonesia must be processed to improve the quality, otherwise it is forbidden to export.

In 2006, Kobe Steel Ltd. reached agreement with PT Bumi Resources and its subsidiary PT Arutmin and constructed a commercial demonstration factory in Satui, South Kalimantan for UBC briquette products with capacity of 600t/d. Japan Coal Energy Center provides the funds. The project started construction in May 2007 and put into operation in Dec. 2008 with total investment of JPY 8 Billion (amounting to 70 Million USD). The UBC process developed by Kobe Steel Ltd. can improve the brown coal quality by dehydration, increasing the heating value through light oil. After improvement, the heating value of brown coal can reach to 27208kJ/kg, 130% as much as the raw coal, and equal to the heating value of bituminous coal while the ash content is only 1/3 of the high-rank bituminous coal. This process can also control the spontaneous combustion tendency of the raw coals so as to solve the difficulty of transportation and storage and make the fact that upgraded brown coal becomes the substitute of high-rank coals possible.

## **2.6 Investigation Report for Coal Comprehensive Utilization of Developed Economies**

During August to September, 2013, the project contractor invited expert from IEA from USEPA, IEA, World Bank, etc. to conduct in-depth technical exchanges in China, discussing the advanced coal comprehensive utilization technologies and policy information in developed economies, including United States, Germany, UK, Australia, etc.

### **2.6.1 General situations of coal comprehensive utilization**

The developed economies has paid special attention to the utilization of coal associated resources of coal and the wastes generated during coal utilization, which will be sold or used directly as resources. CBM is connected into the pipeline network as natural gas, used to make LNG or for power generation. The fly ash, as one of the resources with higher utilization value, is almost used in the fields of building materials industry and construction engineering. The coal gangues are more often used in gob backfilling, road works or as building materials and fuels.

#### **(1) CBM comprehensive utilization**

Since United States firstly succeeded to mine the CBM in 1980s, all other economies begun to explore the CBM in succession. As per the analysis by IEA, the technical recoverable CBM resources in the world can reach 1050Tcf, and about 90% are distributed in the 12 major coal-producing economies (Table.2-2). The major coal-producing economies such as Australia, Canada and Russia started to develop the CBM affected by the successful cases of CBM commercial development in United States, and meanwhile formulated corresponding incentive and supporting policies or rules so as to promote the formation and development of CBM industry. In terms of utilization, United States mainly injects the CBM to natural gas pipeline system and uses it to produce auto fuels, synthesis ammonia and methyl alcohol, etc. Germany, France, Canada, Russia, Australia and Japan mainly use it for power generation.

**Table.2-2 Statistics of technical recoverable CBM resources of the world**

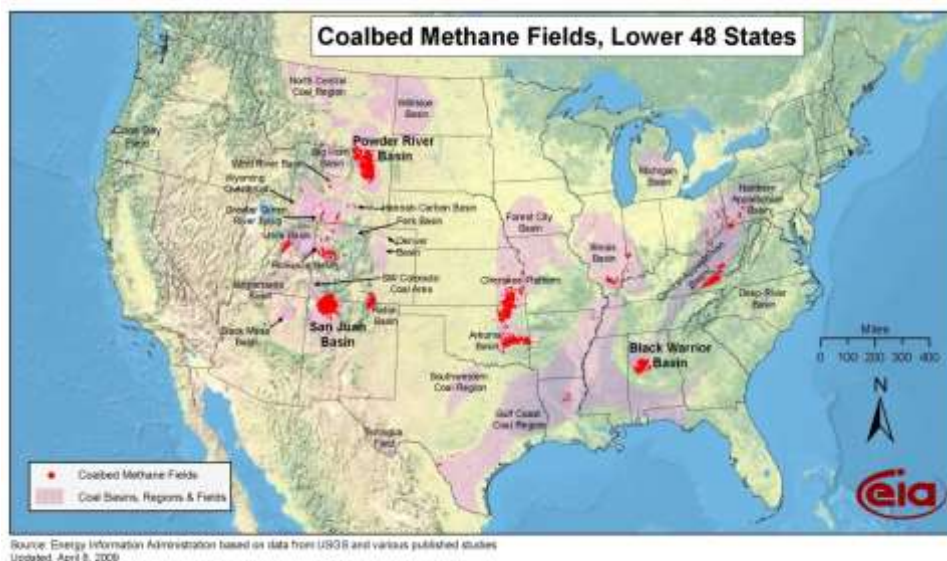
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No.	Economy	Total reserves/(Tcf)
1	China	385
2	U.S	140
3	Australia	439
4	Canada	45
5	Mexico	4
6	Others	2
Total		1050

\*Source: ARI, 2013

According to the statistics released by ARI, the technical recoverable CBM reserve of US reached 140Tcf, mainly distributing in eight explored basins of San Juan, Black Warrior, Raton, Middle Appalachia, Powder River, Unita, Cherokee and Acoma. Till the end of 2011, the annual production of CBM has reached 1763Bcf, accounting for around 8% of natural gas consumption in United States. It is an important energy industry in the US.

The major market for CBM in US mining area is injecting CBM into natural gas pipeline, and it is also popular to use the CBM for power generation. The natural gas pipeline coverage rate in US is very high. The US government canceled the control of pipeline companies over natural gas purchasing and selling market in May 1992. The CBM can be injected into natural gas pipelines as long as it meets the condition that CH<sub>4</sub> content is higher than 95%. The CBM manufacturers have multiple choices to sell the CBM, and can freely select CBM users and natural gas pipeline companies. Therefore, most of the CBM mined in US enters the national natural gas pipelines, and then it will be supplied to users.



**Fig.2-20 CBM distribution in United States**

The CMM drained and recovered from the gob area is generally used for power generation. After mixing the CMM (with methane content of about 30%) with air, it can be used to generate power by gas turbine, combustion engine and gas turbine. The other way is to mix the CBM with coal in boiler for combustion to provide heat and generate power. The CBM added in the boiler can be 10%~100% of the total fuels. It is suitable for the mines locating near power plant or industrial boilers. Some coal preparation plants supporting to the mine well also take CBM as the fuel instead of coals. The recovered CBM is used as fuel for thermal dryer of coal preparation plant at a mine in Virginia, US. Besides, the recovered CBM can also be used for floor facility indoor heating, bathroom hot water and thermal power plant fuels.

Australia is one of the economies earliest drained and used the CBM in mining areas. Its CBM resource is abundant, and the technically recoverable CBM reserve reaches 439Tcf, accounting for over 12% of economically exploitable natural gas reserve in Australia. The CBM resource in Australia is mainly distributed in the black coal wells in New South Wales and Queensland, nearing the potential market in the east coastal areas with intensive population. Moreover, Australia has the industrial policy that CBM extraction is superior to coal mining, and the mine safety rules. All those reasons promote the rapid growth of Australian CBM industry in recent years. In 2011, the output of CBM in Australia was 0.6Bcf Billion m<sup>3</sup>, and dozens out of the 100 coal mines drained the CBM. The drainage volume is larger than 25000 l/s with the methane concentration is 60~70%. The CBM industry in Australia has entered the



**Fig.2-21 CBM surface well in Queensland, Australia**

In terms of utilization, the CBM drained on ground is mainly used to produce LNG. At present, there are 3 LNG manufacture projects by CBM liquidation are under construction. The planned total output is about 25Mt/a. The low-concentration CMM drained underground is mainly used for power generation. Since 1986, Australia started constructing the demonstration project for CBM power generation, and has established the earliest VAM utilization demonstration project in the world. Now there are seven low-concentration CMM power plants connecting to grid with total installed capacity of 215MW, and annually reducing 6.5Mt carbon dioxide equivalence emission. Appin Mine CBM power generation project is representative. This project is one of the largest scale greenhouse gas emission reduction projects in Australia constructed by BHP Billiton. The entire system uses mine VAM as the combustion air. It started operating with full load since 1996, and reduced 3Mt carbon dioxide equivalence emission each year.



**Fig. 2-22 CBM extraction, utilization and transmission pipeline in Australia**

Germany mainly develops and uses the CMM from the closed mine shafts, encourages the utilization of CBM and offers subsidies to the CMM consumers. In 1998, the heating and power plants using the methane drained from the closed mine shafts in Montesness succeeded to operate. RAG acquires CMM with methane concentration of 50% each year in Saarland for thermal power business. The gas turbine and steam turbine are jointly operated to generate power. In 2003, RAG developed new container-structure power, heat supply and cooling coupling unit using CMM as the fuel. At present, Germany has constructed multiple heating and power generation projects by mine methane with total power generation capacity of 6Mkw. Encouraged by various preferential policies, a lot of heating and power generating projects with capacity of 30000kw~50000kw are put into operation successively.

**(2) Fly ash comprehensive utilization**

The use of fly ash as a pozzolanic ingredient was recognized as early as 1914, although the earliest noteworthy study of its use was in 1937. Since 1940s, the fly ashes began being used in repairing reservoir dam project officially. Major uses of

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coal ash include concrete, gypsum wallboard, blasting grit, roofing granules, and a variety of geotechnical and agricultural applications. The fly ash resource utilization in foreign economies has been paid high attention to. The large power plants in developed economies have purified the flue gas. The ash dry discharge and dry ash humidifying have been included in the plan of the power plants. Both the clean power generation and resource utilization for the fly ashes can be reached. The comprehensive utilization rate is very high. For instance, in Netherlands, the rate is 100%, 92% in Italy, 90% in Denmark, and 73% in Belgium. The fly ashes are mainly used in road works, cement and quality concrete production, brick manufacturing and other fields like building materials.

In the past, fly ash was generally released into the atmosphere, but pollution control equipment mandated in recent decades now requires that it be captured prior to release. In the US, fly ash is generally stored at coal power plants or placed in landfills. There is no U.S. governmental registration or labeling of fly ash utilization in the different sectors of the economy -industry, infrastructures and agriculture. In 2011, 43.50 percent of the 130.1million tons of coal ash produced was beneficially used. It also reduces the need to manufacture cement, resulting in significant reductions in greenhouse gas emissions. About 11 million tons of greenhouse gas emissions were avoided by using coal ash to replace cement in 2011 alone.

The way always used in the US is that the fly ash comprehensive utilization companies provide professional services for the fly ash generated in the coal power plants. In terms of utilization, the US divides in details. For instance in the metallurgy field, fly ash is used in founding moulds to produce the castings for buses. In fine chemical engineering field, the fly ash is used as the fillers of polymers such as chemical fiber carpet underlay. In the road construction field, the asphalt concrete is added with fly ash to pave the roads in rural gravel road reconstruction, and the fly ash is used as fillers on a large scale in airport runway construction. In building material field, the fly ash raw materials start to substitute the traditional building materials and are used in wallboard and hollow stone pillar to replace the bricks and tiles. The F-class fly ash can be used to manufacture the burrs, the composites of fly ash and fibers are used to produce materials for wall, and 100% fly ash is used to produce high performance blocks, etc. Although the approaches are few, the US pays

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attention to the scientific and technological utilization of fly ash, and studies in depth.

The bulk utilization has higher technology content and meticulous division, the utilization is stable and has a world leading position in relevant application fields.

The fly ash output of Japan in 2007 was 12Mt, among which 11.6Mt has been effectively used with utilization rate of 97%. The fly ash disposition methods of Japan are comprehensive utilization and landfill. Based on environmental protection and resource reclamation, Japan greatly develops the comprehensive utilization technology. In 1955, it firstly used the fly ash in the dam. During 1955 to 1968, it constructed 27 fly ash concrete dams in total. Later, the fly ash is used in quantity in civil buildings, roads and bridge engineering projects. Now, the fly ash in Japan is mainly used in cement and concrete fields, as well as other fields such as civil engineering, building materials, agriculture, forestry and aquaculture. The components, physical and chemical features of the fly ash are mainly used to improve soils and make fertilizers. Moreover, the physical and chemical adsorption property of the fly ash is used for acid mine wastewater processing and flue gas desulfurization.

### **(3) Coal gangue comprehensive utilization**

Since 1960s, the comprehensive utilization of coal gangues has attracted attentions of many economies. Till 1970s, the coal gangue utilization rate in economies such as France and Germany had reached 30%~50%. The developed economies have more complete regulations and administrative methods for the processing of coal gangues, organs engaging in coal gangue processing and utilization has been established, thus harmless processing has been basically realized. The coal gangues are mainly used in gob backfilling, construction engineering filling, road works and useful components recovery or as fuels, building materials or for soil improvement.

The US Bureau of Mines started to conduct sampling analysis for all gangue dumps since 1970s, and made comprehensive utilization plan for coal gangues. The US uses the red gangues as building materials, which is the mean with largest coal gangue consumption. In Pennsylvania, the “red gangues” are used for road surface works.

As building material, coal gangues, compared with other materials, are superior in



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reinforcing flood control dam, retaining wall and embankments. The coal gangues are often used to reinforce the flood control dam, retaining wall, drainage way and embankments in German water projects.

The annual output of coal gangues in France is about 8.5Mt. The French government started to formulate coal gangues sales plan since 1970. For years, about 115Mt coal gangues are utilized in total. The coal gangues are mainly used to manufacture bricks and produce cements. The Süstedt Brick Factory in Wulong District uses about 100,000t gangues each year. 32Mt coal gangues with ash content of 65%~70% were also washed and prepared, and recovered 8.4 Mt combustibles for power generation, equal to saving nearly 4Mt coals.

### 3. Study on coal comprehensive utilization modes in APEC economies

Based on the investigation and analysis, the comprehensive utilization modes of coal is studies, and the advantages, disadvantages, feasibility and benefits of different utilization approaches of CBM/CMM, coal gangue, fly ash and coal associated minerals are analyzed and summarized from the aspects of technology, economy, society, etc. The challenges that APEC developing economies may face in the processes of promoting coal comprehensive utilization are put forward.

#### 3.1 Study on CBM/CMM comprehensive utilization mode

CBM is commonly known as gas, which is a kind of gas resources accompanying with coal, and its main component is  $\text{CH}_4$ , is a kind of potential clean energy with very rich reserves. According to the estimate of International Energy Agency (IEA), the CBM resources in the world can reach  $260 \times 10^{12} \text{m}^3$ , of which about 90% is distributed in 12 major coal producing economies, and the CBM reserves of APEC economies of Russia, Canada, China, USA, Australia, etc. respectively exceeds  $1 \times 10^{13} \text{m}^3$ . Since US successfully developed CBM during the end of 1970s to the beginning of 1980s, Economies in the world competed for developing CBM. After many years' development, CBM industry has been formed within some APEC economies.

CBM is not only clean fuel and chemical material, but also a kind of strong greenhouse gas with greenhouse effect 21 time as much as  $\text{CO}_2$ . At the same time, it is the killer of coal mine accidents. The comprehensive utilization of CBM resources is greatly significant to form CBM new energy industry, improve coal mine safety production conditions, and reduce gas accidents and greenhouse gas emission.

##### 3.1.1 Technical approaches for CBM/CMM comprehensive utilization

According to the investigations, the technical approaches of CBM resources utilization at present include pipeline transportation, compression and liquidation, household use, industrial fuel or raw materials, automobile fuel, power generation, etc.

### **(1) Pipeline nature gas**

According to different mining methods, CBM resources can be divided into CBM developed by surface drilling wells and CMM drained from underground coal mines. The methane concentration of CBM is usually over 98%, with its main components same as conventional nature gas, which can be directly connected into nature gas transmission pipeline through simple treatment like dehydration, etc. after being mined.

The main market of CBM in the US is to transmit into nature gas pipeline. Its nature gas covering rate is very high, all the CBM with its CH<sub>4</sub> content over 95% can enter the nature gas pipeline. CBM manufacturer can have many selections to sell CBM, and can freely choose users and nature gas pipeline companies. In China, China National Petroleum Corporation has firstly transmitted CBM drained in Shanxi Qinshui Basin into the main line for West-East natural gas transmission with annual capacity of  $6 \times 10^8 \text{m}^3$ , which realized the joint transmission and joint use of CBM and nature gas.

### **(2) Liquefied natural gas (LNG)**

CBM/CMM liquidation means the process of CBM/CMM from gaseous state to liquid state after being purified and refined under certain temperature and pressure. The volume of CBM /CMM after being liquefied will be shrunk for 600 times, which will greatly reduce the transportation costs. Tank car transportation of LNG can change the transportation approach with the change of gas sources and users, and also can be used as the peaking resources of existing nature gas pipeline.

CBM with the methane concentration above 90% can be directly pressurized and copious cooling liquefied into LNG after decarburization, desulfuration and dehydration. Generally, CMM has lower methane concentration and contains oxygen, it may cause explosion if it is directly pressurized and liquefied, processing separation technologies like adsorption and resolving separation, permeating separation and low temperature separation, etc. should be adopted to separate and splitting liquefy the oxygen-bearing CMM, and purified to obtain LNG products.

### **(3) Compressed nature gas (CNG)**

CBM/CMM can be deoxidized and compressed into CNG product. Processing separation technologies like adsorption and splitting separation, permeating separation and low temperature separation, etc. also can be adopted to purify and compress nature gas. The CNG product not only can meet the local demands, but also can be considered to be transported out for selling, but the radiation distance is less than that of LNG product.

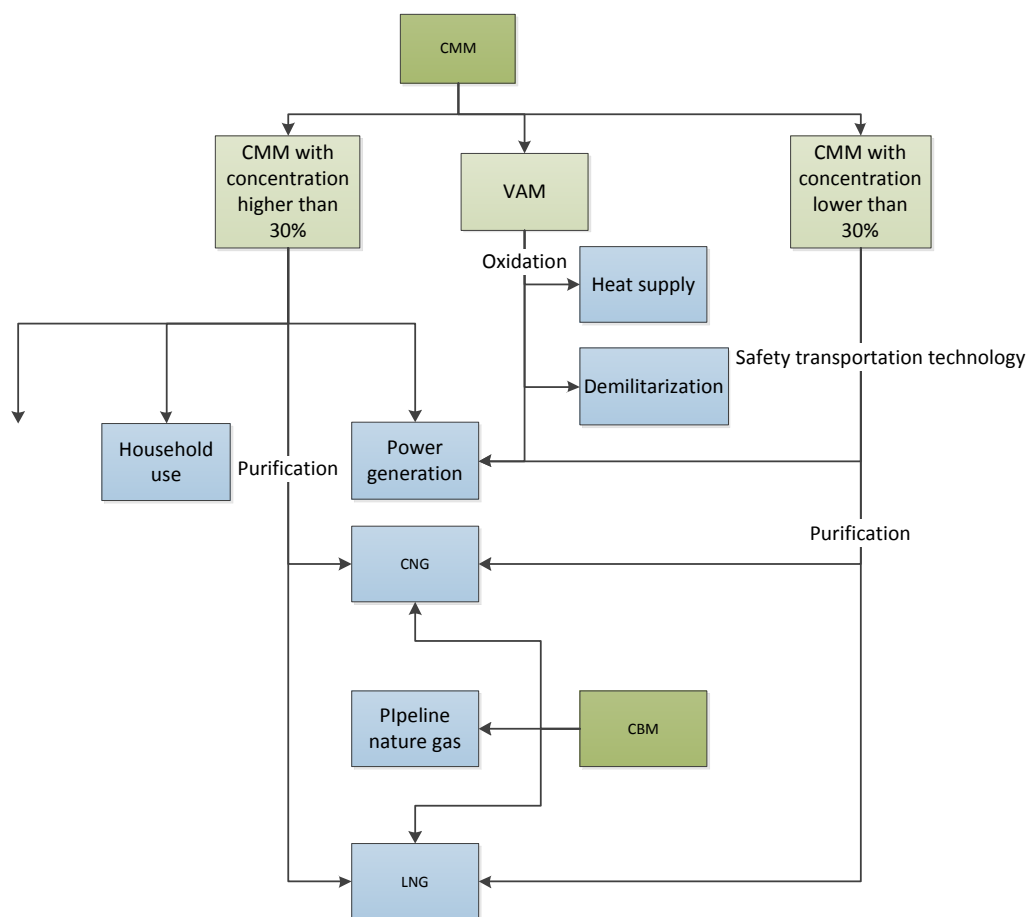
### **(4) Household use/industrial utilization**

CBM/CMM for household use has the advantages like obvious energy saving effect, less initial investment, large market use potential, etc. CMM is generally utilized as civil fuel, which is transported to the houses of the residents via low pressure pipeline network under stable drainage capacity and methane concentration  $\geq 30\%$ . Industrial utilization includes substitution of coal-fired boiler and producing chemical products like carbon black, methyl alcohol, methyl aldehyde, etc. Carbon black is the product under high temperature burning and thermal decomposition reaction; it is the additive of rubber, coating, etc. CMM can be used to product carbon black when the methane concentration is during 40%~90%, and the yield of the carbon black is higher as the methane concentration increase. The methods to produce Methyl aldehyde with CMM includes direct oxidation to be methyl aldehyde, or oxidation to be methyl aldehyde after methyl alcohol is produced by CMM.

### **(5) Power generation**

CMM power generation can effectively transfer the thermal energy of the CBM resources drained in the mining area into electric energy, which can be conveniently transported to the power shortage area. At present, CMM power generation includes power generation with high quality CMM and low quality CMM. The power generation technology using high quality CMM is similar to natural gas power generation, which is mature with wide application. After years' development, the power generation technology using low quality CMM also gradually becomes mature, of which, *Coal Mine Safety Regulation* has been revised in China, and corresponding safety regulations have been completed, which swept off the obstacles of laws and regulations for large scale promotion of low quality CMM.

CMM power generation adopts the main equipment, including steam turbine engine, combustion gas turbine engine, and internal combustion gas engine technologies. The utilization of Ventilation Air Methane (VAM), whose methane concentration is extremely low, usually less than 1%, mainly adopts three kinds of methods, including thermal oxidation, catalytic oxidation and being used as auxiliary fuel. Thermal oxidation has realized industrialization operation and is a kind of mature technology.



**Fig.3-1 Technical approaches for CBM/CMM utilization**

### 3.1.2 Key technologies for CBM/CMM comprehensive utilization

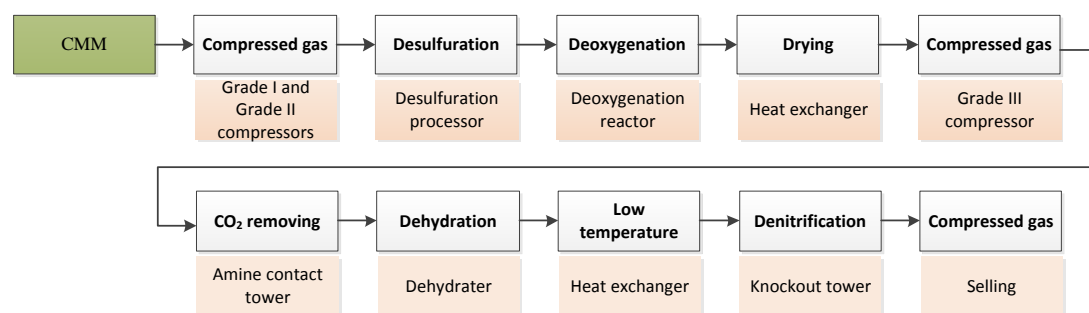
In recent years, with gradual improvement of various technologies, CBM/CMM comprehensive utilization technology system covering all kinds of methane concentration has been formed on the whole. According to different utilization approaches, the utilization technologies with rapid development are mainly concentrated in processing separation and conversion and utilization. CBM/CMM after being processed and purified can be liquefied or compressed to produce LNG or CNG products. CMM with different methane concentrations can be converted into electric energy via internal combustion gas engine, gas engine, etc. VAM with the

methane concentration less than 1% also can be utilized or destroyed via different oxidation technologies. Effective utilization of CMM with the concentration less than 30% is always a key point of CMM utilization technology development. Especially the continuous development of the safety transportation technologies, etc. of CMM with methane concentration within the explosion range provided powerful technical support for CMM large scale utilization. The summarized key technologies for CBM/CMM comprehensive utilization can be divided into the following points:

**(1) Processing separation technology**

The effective way for liquefying and compressing CMM is processing separation. At present, the main methods for CMM processing purification include adsorption and resolving separation, permeating separation and low temperature separation.

Adsorption and resolving separation utilizes different diameters of various gas molecules in the CMM and different natures of some certain substances properties to absorb some molecule when air flow passes adsorbent. It should be resolved out after adsorption saturation, so as to separate with the other gas molecules. Molecular sieving, pressure swing adsorption, etc. belong to this kind of separation. Permeating separation is to let the CMM pass the permeating device with membrane. Small gas molecules can pass the membrane, while bigger gas molecules cannot. The gas in different sides of the membrane will be collected, so as to achieve the separation. Low temperature separation is to condense the gas mixture into liquid, and then they should be separated according to the different evaporating temperatures of the components. At present, low temperature separation are applied in certain range, the main representative technologies include Nitech<sup>TM</sup> technology and cryogenic distillation technology.



**Fig.3.2 Treatment processing flow of Nitech<sup>TM</sup> technology**

Nitech<sup>TM</sup> technology is used for removing N<sub>2</sub>, O<sub>2</sub> and other impurities in CMM. From the principle separating N<sub>2</sub>, this is a kind of low temperature separating technology. Before entering the low temperature system, O<sub>2</sub> should be firstly separated in advance, to guarantee the safety performance of the liquidation procedure, and lowered the energy consumption of the system in certain degree. O<sub>2</sub> removing is converted into CO<sub>2</sub> and water mainly via contact-type converter, and remove CO<sub>2</sub> and water via amine contact tower and dehydrating unit, shown in Fig.3-2, so as to obtain high purity methane. This technology is successfully applied in part of the coal mines in the US.

Cryogenic distillation technology compresses CMM via compressor to increase the pressure, enters molecular sieve and meanwhile separates water and CO<sub>2</sub>, and then enters cooling system for cooling treatment after passing through drying system, the cooled gas enters the middle part of the fractionating tower. It is evaporated in the evaporator on the bottom of the fractionating tower and condensed in the condenser on the top, and the gas fraction and liquid fraction in the tower are sufficiently carried out with mass and heat exchange, high purity nitrogen will be obtained on the top of the fractionating tower, and high purity liquid methane will be obtained on the bottom of the fractionating tower. This technology has been successfully applied in part of the coal mines in China.

## **(2) Converting utilization technology**

In recent years, CMM power generation projects are developed rapidly. CMM power generation with the methane concentration over 30% mainly adopts power generation units with internal combustion gas engine, and this technology is mature and widely used. While the CMM power generation with the concentration lower than 30% is the hot spot and technical tackling difficult point in recent years. At present, the mature technologies include internal combustion gas engine technology, thermal counter flow reactor, etc.

### **a) Internal combustion gas engine**

The working principle of internal combustion engine is that CMM and air are mixed to the methane explosion limit (5%~15%), which should be detonated for acting in the

anti-explosion cylinder. It drives piston motion, so as to drive the synchronous generator for power generation. There are 2 types of gas engine: one is spark ignition four-stroke engine, and the other is Searle double fuel engine. Compared with other CMM power generation technologies, internal combustion gas engine has high power generation efficiency, generally during 32%~40%, with compact structure, light single machine mass, convenient for moving, flexible for station construction, short period, etc. The fuel gas for internal combustion gas engine should be pressurized, and the one-time investment is high, as well as the maintenance fee. At present, the main manufactures of internal combustion engine power generation units include Caterpillar, Commins, Wartsila from Netherland and Shengdong Group from China, etc.

#### **b) Gas engine**

Specific to the features of unstable methane concentration and large pressure fluctuation of low quality CMM, gas engine utilizes electronic control system to provide accurate control signals in fuel supply system, and realize the accurate control to the air-fuel ratio via the air and gas flow rate controlled by stepping motor, i.e.: the volume ratio between methane and oxygen is 1:2. During the unit operating process, the methane concentration should be controlled within the explosion limit of 5%~16%. After being electronically ignited, the mixed gas is sufficiently exploded and acted in the cylinder, and the pistons of the internal combustion engine are in reciprocating motion up and down to drive crank axle rotating. Thus, the generator rotor cuts the magnetic line of force to generate electric energy. Gas engine possesses the advantages such as small size, low weight, high thermal efficiency (it can reach 40%), strong adaption for CMM concentration change, etc., and it is generally suitable for small size power plant.

Besides, other methods like medium and large gas turbine, micro gas turbine, combined heat and power generation, etc. can be used for CMM power generation, which the adaption, heat efficiency, installed capacity, etc. of the fuel gas will be different.





**Fig.3-3 CMM power generation units**

### **c) Thermal counterflow reactor**

This technology developed by MEGTEC is mainly used for coal mine VAM power generation with the methane concentration lower than 1%, and its core part is VOCSIDIZER. It consists of a single steel container inside of which is a ceramic bed. The heating elements locate in the middle of the ceramic bed. The working principle of VOCSIDIZER is as follows: the bed is initially heated to 1000°C. The VAM is then introduced into the bed. As the gas move through the hot space in the middle of the bed, they are immediately oxidized, and through heat exchange, the oxidizing energy can be transferred around the bed. If methane concentration in VAM reaches some balance point, then, the system can maintain its own operation without external heat, while this balance point is the energy generated from methane oxidation in VAM equals to the heat loss of the reactor itself and part of the energy taken away by outlet gas. If the methane concentration in VAM is higher than the balance point, the excess energy of the reactor in continuous heating and operation can be exported via heat exchange. The exported energy can be used in many fields, and the most general selection is for power generation. This technology has successfully applied in some coal mines in China and Australia.

From classification, thermal counter flow reactor belongs to thermal oxidation technology, and its corresponding technologies for VAM utilization also include catalytic oxidation technology and auxiliary fuel combustion technology. Catalytic counter flow reactor is the representative of catalytic oxidation technology, and its

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basic working principle is same as that of thermal counter flow reactor. The different is that it is equipped with catalytic media at the upper and lower sides of the central high temperature area. Under the function of catalyst, methane can be oxidized and release energy under lower temperature ( $600^{\circ}\text{C}$ ). Same as heat counter current reactor, the gas inlet direction should be successively changed to maintain the stable high temperature in the central area, so as to reach the purpose of continuous operation.



**Fig.3-4 VAM power generation project in Australia**

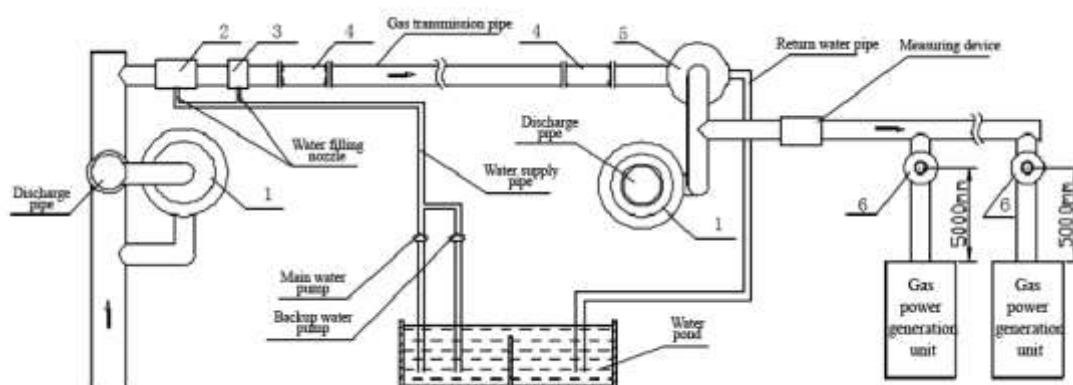
### **(3) Safety transportation technology**

Theoretically, concentration during 5%~16% belongs to the methane explosion range. In practical production, due to the influence by temperature, mine dust, etc., the actual concentration explosion range will be much wider. Generally, the low quality CMM with the methane concentration lower than 30% cannot be directly transported, and special technology should be adopted to effectively resolve the explosion prevention problems. At present, the mature low quality CMM transportation technologies include gas-water two-phase flow transportation technology and gas water mist transportation technology.

#### **a) Gas-water two-phase flow transportation technology**

In the horizontal direction of transmission pipeline, the water flow will be flowed in the internal wall of the transmission pipeline via ring flow device to form ring surface water seal. The gas flow flows within the internal wall ring water flow cavity, and the low quality CMM is in forward and continuum flow along the transmission pipeline completely under surrounding of the ring water flow. In the vertical direction of the

transmission pipeline, intermittent plunger water mass is generated in each 30~50m interval along the flow direction via column flow device, so as to form end surface water seal, and divide the flowing gas flow into segments in pipeline internal wall ring water flow cavity. Low quality CMM forms a intermittent plunger gas flow on the ring surface and end face, and forms safe and stable gas-water two-phase flow in transmission pipeline, which effectively realizes flame and explosion retardance, and guarantees the safe transportation of low concentration gas. This technology is mainly used for positive pressure pipeline network transmission, see Fig.3-5, it has been well applied in Anhui Huainan Mining Area and part coal mines in Guizhou in China.



1 – Pressure regulating and diffusing device, 2 – Column flow device,  
3 – Ring flow device, 4 –Transparent observation pipe,  
5 –Anti-explosion fire retardance gas-water separator, 6 –Two-way fire retardance device

**Fig.3-5 Low quality CMM gas-water two-phase flow safety transportation system**

### b) Gas water mist transmission technology

Water mist is composed by the fog drops with the fog drop volume larger than 50% and average diameter less than 400 $\mu$ m. Low quality CMM is continuously transmitted in the pipeline after being sufficiently mixed with water mist via the devices like water mist generator, etc. Due to the specific surface area and density of the water mist fog drops are high, which can be rapidly vaporized after meeting the high flame temperature, and the volume can be expanded to be more than 1700 times, which will greatly decrease the oxygen concentration in the protective area, and absorb large amount of heat, so as to realize the three purposes of cooling, oxygen separating suffocation and thermal radiation isolation. Therefore, possible static during pipeline transmission and fire sources in pipeline caused by nature or human factors can be effectively eliminated, and it can rapidly knock down the flame in the pipeline and

effectively prevent forward and backward spreading of the flame. This technology has been widely applied in part of the coal mines in China.

Besides above two successful applied transmission technologies, there are some safety transmission technologies under test stage, including steam safety transmission technology and inerting activating safety transmission technology. The main principle is to enable the gas to lose the explosion property via adding inflaming retarding media with certain volume percentage, so as to realize the intrinsic safety transmission, or special device is installed at the gas input port to inactivate the explosion of the gas inerting, which should be transmitted into the outlet installed with active device to enable it to recover the explosion property. This kind of technology should be further studied and applied.

### **3.1.3 Comprehensive benefits of CBM/CMM utilization**

CBM/CMM comprehensive utilization is beneficial for reducing CMM disasters, improving atmosphere environment, guaranteeing energy security, therefore, it has multiple comprehensive benefits.

#### **(1) CBM/CMM comprehensive utilization to reduce gas accidents**

Coal mine methane is the biggest hidden danger for coal mining, which may easily cause huge safety accidents. With the increase of the coal output in APEC economies, the hazard created by CBM/CMM is also larger. Gas accident reduction is one of the key problems to increase the safety of coal mining activity.

The function of CBM/CMM comprehensive utilization to reduce coal mine accident mainly reflects in gas explosion accident reduction. Effective utilization of drained CBM/CMM, increasing the drainage strengthen of coal mine, and decreasing the methane concentration in the coal mine within the safety range can decrease the frequency of safety accident occurrence.

#### **(2) CBM/CMM comprehensive utilization to reduce greenhouse gas emissions**

Hazard brought by greenhouse effect has become the common view. At present, carbon dioxide is the largest greenhouse gas, and its emission takes more than 60% of

the total emissions of the greenhouse gases in the world. Compared with carbon dioxide, methane is another important greenhouse gas only next to it. Its concentration is small in the atmosphere, but its growth rate is much larger. In addition, in contributions to the greenhouse effect, methane GWP is 21 times of that of carbon dioxide, so you can see the influence degree of methane to greenhouse effect. Therefore, methane emission control is very important to restrain the functions of greenhouse effect.

Coal mining is one of the main activities of the methane emission, and large amount of unutilized methane is directly emitted into atmosphere every year, which causes pollution to the environment. The functions of CBM/CMM comprehensive utilization to greenhouse gas emission reduction are mainly reflected in methane emission reduction during coal mining.

### **(3) CBM/CMM comprehensive utilization to energy security**

CBM resource has same usage as that of nature gas on the whole, which can replace the petrolic function in part of the fields, which makes it one of the alternative energy sources. Therefore, CBM is a kind of most realistic gas resources in recent period, with huge development potential, and can reliably relieve the situation of oil shortage. The functions of CBM/CMM development and utilization to the energy security of APEC economies are mainly reflected in replacing petroleum and nature gas, so as to reduce corresponding strategic oil reserves.

#### **3.1.4 Encouragement policies for CBM/CMM utilization of APEC economies**

Besides depending on the technical development support to accelerate CBM/CMM utilization, various active encouragement policies presented by the government also play an important role. APEC economies with rich CBM resources, including USA, Australia, China, etc., have issued a series of corresponding encouragement policies.

United States is one of the important economies with abundant CBM resources , and also the most successful economy for CBM commercial development in the world, and the US government also issued many encouragement policies on aspect of CBM utilization. 1605(b) terms of *Energy Policy Law 1992* issued by US Congress

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stipulates that electric power department can obtain concessional loan when their carbon dioxide emissions are reduced and the coal consumption is changed into CBM consumption. *Guide of Federal Government on CBM Project Funding* issued by US Environment Protection Agency in March 1996 provides concessional loan to CBM development and utilization projects. It provided concessional loan, loan guarantee and aid fund to rural CMM projects via setting up assisted projects of Ministry of Agriculture, and its main objects were application projects of new technology and meager profit projects in rural area. Loan guarantee with the total amount 849 million USD were provided during 1993 to 1995. The assisted projects of Ministry of Commerce financially aid to the CMM power generation, pipeline gas transmission, sale or resident gas projects using CMM from gassy coal mines, and it totally provided aid funds of 46.1 million USD during 1992 to 1994.

In order to resolve coal mine safety issues, and reduce methane concentration, Australia actively encourages developing CBM industry. The economic policies on aspect of CBM/CMM development and utilization in Australia includes *Queensland Energy Policy – Clean Energy Policy* issued by Queensland government, which requires that the gas power generation takes 13% of the total power quantity, and it greatly stimulated CBM development and utilization.

Chinese government pays close attention to CBM/CMM development and utilization, and the leveling function of preferential measures. *Comments of General Office of the State Council on Further Accelerating CBM/CMM Drainage and Utilization* issued in 2013 emphasized the comments of eighteen articles such as increasing financial fund support, strengthening tax policy support, completing CBM price and power generation grid interconnection policy, strengthening CBM/CMM development and utilization management, promoting technological innovation, strengthening organization leading, etc., so as to encourage large scale development and utilization, and play accelerating role to CBM/CMM comprehensive utilization.

CBM/CMM subsidy policies in China are mainly on aspect of power generation. It presented in *Notice of Implementation Suggestions of CBM (CMM) Power Generation Work Printed and Issued by National Development and Reform Commission* (FGNY

(2007) No. 721) issued in 2007 that CMM power plant will not participate in market bidding, and will not assume grid peaking tasks. The on-grid tariff of CMM power plant should be based on the on-grid tariff of biomass power generation projects in *Trial Method of Allocation Management of Renewable Energy Power Generation Price and Expenses* formulated by National Development and Reform Commission. Subsidiary electricity tariff standard is RMB0.25/KWh. Subsidiary electricity tariff will be enjoyed for power generation project within 15 years since the date of putting into operation.

As for the low quality CMM transmission and power generation field having greatly developed in recent years, Chinese government made corresponding modification to existing policies. China State Administration of Work Safety issued *Decisions on Part Terms of Modification on Coal Mine Safety Regulation* in 2010, of which, according to issued relevant standards of low concentration gas safety utilization, the stipulations in original *Regulation* on CMM with methane concentration less than 30% should not be used is revised into CMM with methane concentration less than 30% should not be used as gas for direct combustion. When it is used for internal combustion engine power generation or other purposes, CMM utilization and transmission should be based on relevant standard stipulations, and safety technical measures should be formulated. The limits of low quality CMM for internal combustion engine power generation and utilization after concentration are abolished. In same year, the State Administration of Work Safety issued 10 items of low concentration gas transmission and utilization safety production industry standards, including safety technical conditions for non-metal gas transmission pipeline of coal mine, technical conditions for automatic anti-explosion device of gas pipeline transmission, design code for safety guarantee system of coal mine low quality CMM pipeline transmission, technical code for coal mine low quality CMM and water mist mixture safety transmission equipment, etc., which have been started for effectiveness since July 1<sup>st</sup>, 2010.

### **3.1.5 Challenges for APEC developing economies on CBM comprehensive utilization**

APEC developing economies have rich CBM resources, and in recent years, the

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governments also actively encourage CBM resources development and utilization, but the utilization rate is generally low from existing situation. The existing problems include non-coordinated technologies and infrastructures, backward management consciousness, incentive system shortage, etc.

1) In recent years, major breakthrough has been achieved for CBM development and utilization technologies, some hot spot fields like scientific research and problem tackling as well as investment and development appeared. However, compared with the developed economies like US, Australia, etc., the developing economies invested less to new technology application and R&D of corresponding technologies, and many technical problems have not been effectively resolved.

2) Coal enterprises' consciousness to CBM comprehensive utilization is weak, and corresponding policies are not complete. Environmental protection regulation for methane emission reduction and development and utilization policies for encouraging CBM as clean energy are not complete. For instance, most of the existing regulations and mandatory standards only emphasize CMM drainage from safety reason, but fail to provide guidance for enterprises to consciously carry out the utilization. Only some coal companies with large drainage volume will consider it as an industry. When CMM drainage volume is enough to guarantee the demand for safety production, almost all the coal companies will not consciously carry out production layout from comprehensive utilization viewpoint. Therefore, CBM utilization cannot be well promoted in these APEC developing economies.

3) CBM industrial supporting policies cannot be effectively implemented. In China, the government has issued corresponding encouragement policies focused on coal mine safety and CBM/CMM development and utilization, but on one hand, failure of issuing more preferential policies has influenced the enthusiasm of coal companies to utilize CBM/CMM in certain degree, on the other hand, the actual implementation effect is not very well even if a series of encouragement policies have been issued recently.



### **3.2 Study on coal gangue comprehensive utilization mode**

Coal gangue is the mixture of many kinds of ore rocks of carbonic rocks and rocks discharged in the coal mine during shaft construction, development and advancement, coal mining and coal washing, and its main ingredients are coal, carbonaceous shale, batt, sandstone, etc. Large amount of coal gangues are disorderly arranged and piled, which not only occupies large area, overflowing or immersion of sulfide in coal gangues also pollutes atmosphere, soil and water quality. When coal gangues are in spontaneous combustion, large amount of noxious gas emissions will create pollution to atmospheric environment.

Fly ash is the solid waste discharged in coal-fired power plant, and it is the powdery materials collected by dirt catcher after baring powder coal with certain fineness is combusted in boiler. Generally, average 10,000 kWh of electricity generated will discharge 10,000 tons of fly ash, and combustion of each ton of coal will produce 250~300kg of fly ash. If large amount of fly ashes are not properly processed, it also will occupy large area of farmland and plowland, and the raise dusts generated seriously pollutes the atmosphere. In addition, the underground water system in the piling area also will be polluted due to eluviation, and its grout is discharged into rivers and lakes, which will pollute and block the rivers, directly influence the aquatic growth, and damage the ecological balance. Therefore, the comprehensive utilization of coal gangue and fly ash has very important real significance and profound historical significance to protect environment and realize sustainable development.

APEC developed economies carried out study and utilization to coal gangue and fly ash much earlier, such as the policies and regulations for resources utilization to coal gangue wastes by the economies like US, Japan, etc. are complete, and their resources utilization technical level of coal gangue and fly ash is high.

#### **3.2.1 Technical approaches for coal gangue comprehensive utilization**

The carbon content of coal gangue is the main basis for determining its utilization. According to its carbon contents, the utilization ways for coal gangue can be divided into a) the coal gangue with the carbon content less than 10% possesses no resources utilization conditions, which can be used as filling materials for coal mine goaf filling,

subsidence area reclamation, roadbed material, etc. b) the coal gangue with the carbon content during 10% ~ 20% can be used as mixed energy for manufacturing construction materials, like sintered brick, hollow brick, cement, concrete, etc.; c) the coal gangue with the carbon content reaching 20% (i.e. the heat value during 6,270kJ/kg~12,550kJ/kg) can be used as energy, its coal can be recovered, or as the substitute energy for power generation, heat supply, etc. Meanwhile, coal gangue generally will contain large amount of useful minerals, therefore, they can be prepared to be chemical raw materials, etc. through recovering the minerals in the coal gangue.

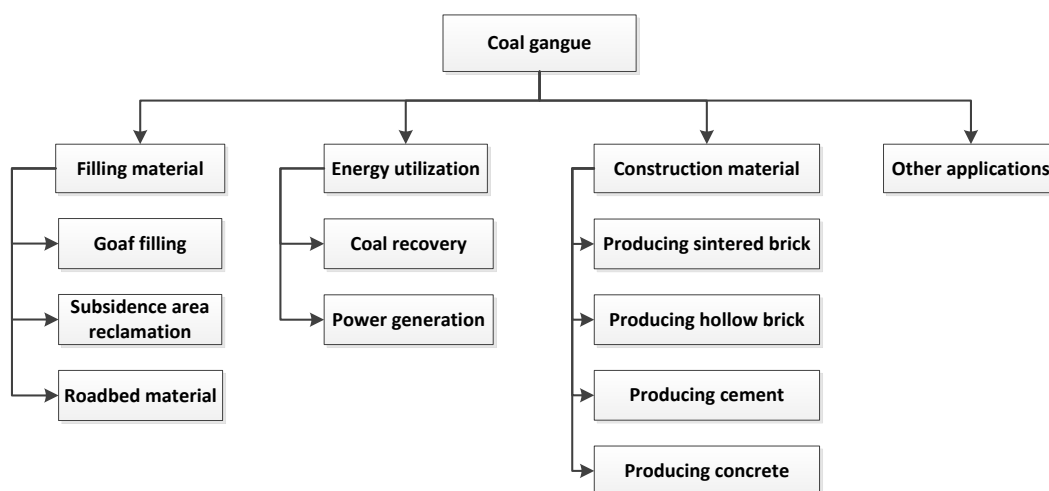


Fig.3-6 Technical approaches for coal gangue comprehensive utilization

### (1) Filling materials

To utilize coal gangue as a filling material is the main utilization way, which is a simple and direct operating method with large utilization quantity.

#### a) Goaf filling

For goaf filling using coal gangue, hydraulic power and wind power filling are usually used. Hydraulic power filling (also called flow and sediment filling) is a kind of general method with utilization of coal gangue for shaft backfill. If the rock components of coal gangue are based on sandstone and limestone, cementing materials like clay, fly ash or cement, etc. should be added in proper amount during backfill to increase the cohesiveness and inertia of the filling materials. When rock components of coal gangue are based on mudstone and carbon mudstone, sands in proper amount should be added to increase the skeleton structure and inertia of the filling materials. The water required in hydraulic filling can adopt the waste water

discharged in abandoned shaft or during coal mining process, and the water separated and oozed after backfill can be reused.

**b) Subsidence area reclamation**

Coal gangue is used for subsidence area reclamation. It mainly utilizes coal gangue and fly ash to fill the coal field subsidence area. On one hand, it avoids the hazards like environmental pollution, etc. caused by the land occupation with large amount of coal gangue piling, nature, etc., on the other hand, it also can resolve the filling materials for the subsidence area, and the land after reclamation can be used for mining area or urban life or production infrastructure land.

**c) Roadbed material**

Coal gangue is a kind of sound roadbed material, combined with the physicochemical properties (such as: granulometric composition, expansibility and disintegration, densification, water stability, permeability, shearing strength, etc.) of the coal gangue and mixed with other materials to enable the coal gangue to be used in the infrastructure like road, railway, etc.

**(2) Manufacturing construction material**

**a) Producing sintered brick.**

The sintered brick produced by coal gangue takes coal gangue as the main materials, which generally takes more than 80% of the ingredients quantity. No additional fuel is needed during the process of the coal gangue is manufactured to be coal gangue brick roasting through breaking, grinding, stirring, suppressing, molding, drying and roasting. Utilization of coal gangue as fuel not only increased the utilization rate, but also reduced the production cost. The carbon contents of all the coal gangues are high, and the heat value generally should be controlled within the range of 2,090kJ/kg~4,180kJ/kg. If the carbon content in the gangue is over high, small amount of clay can be mixed in the raw materials, and over baking bricks should be avoided. Beside certain requirements to the heat value, it also has stipulations to the chemical components of brick manufacture by coal gangue, generally, it requires that SiO<sub>2</sub> content is 55%~70%, I<sub>2</sub>O<sub>3</sub> is 15%~25%, Fe<sub>2</sub>O<sub>3</sub> is 2%~8%, plasticity index is 7~15, and the heat is 315~5MJ/kg. Compared with clay bricks process, grinding

process is added into the coal gangue brick firing process. Jaw crusher or hammer crusher, ball mill, etc. can be selected separately for rough, medium, and fine grinding, and ageing should be carried out to the raw materials to increase the plasticity.

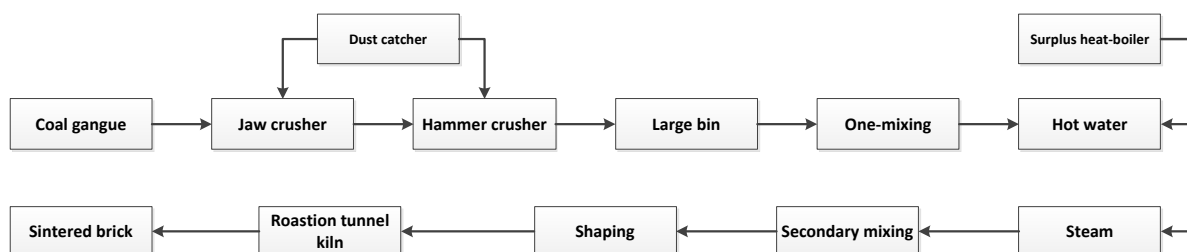


Fig.3-7 Process flow diagram of coal gangue sintered brick

### b) Producing hollow brick

The chemical component requirements to the coal gangue are the same as that of the coal gangue vitrified brick, but its grinding requirements are high, the water content should be during 13%~17%, high pressure extruding machine should be used for molding, and the tunnel kiln should be manufactured in one-time calcining.

### d) Producing cement

Coal gangue can be used as the mixed materials to grind various cements. The coal gangues for cement mixed materials are required to be carbonaceous mudstone and mudstone, sandstone, and limestone (calcium oxide content >70%), generally fired or calcined coal gangue can be selected. The chemical components of coal gangue are similar with that of clay, and it contains certain amount of coal, which can replace clay as the raw material of cement or as mixed materials to directly mix into the clinker, so as to increase the cement output. Please refer to Fig.3-8 for utilization of coal gangue as raw material to produce cement, and its production process is similar with that of clay on the whole. Firstly, after breaking and abrasive cleaning, the raw materials like coal gangue, limestone, etc. are mixed with certain amount of iron powder (or aluminite powder), and then levigated and stirred into raw materials; and then, they should be calcined into cement clinker in rotary kiln, and mixed with gypsum, etc. to manufacture cement clinker.

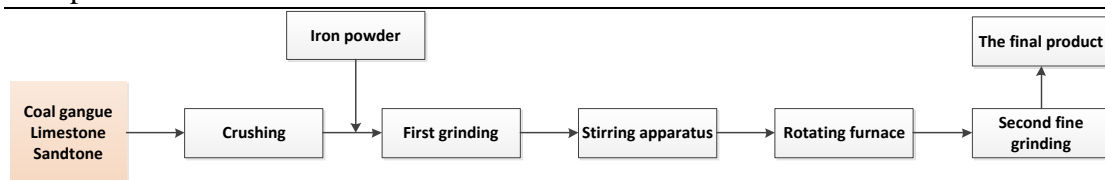


Fig.3-8 Process flow diagram for coal gangue to produce cement

#### d) Producing concrete

Coal gangue produces concrete with utilization of nature coal gangue or sintered coal gangue as concrete admixture, which can improve the performance of concrete, increase the capacity of carbonation resistance and sulfate corrosion resistance of concrete, so as to improve the concrete product and project quality.

### (2) Energetic utilization of coal gangue

#### a) Coal recovery

Existing coal preparation technology can be used to recover the coal resources mixed in the coal gangue, and it is also the preprocessing of energetic utilization of coal gangue and other resources recycling. Before coal gangue resources recycling and utilization, recovery of its coal not only saves energy, but also increases economic benefits. At present, the washing processes of coal recovery mainly include hydrocyclone separation and dense medium separation. Hydrocyclone separation is to enable high carbon content coal gangue to enter the hydrocyclone via constant pressure water tank to separate coal granules and gangue, and to form cleaned coal after dehydration.

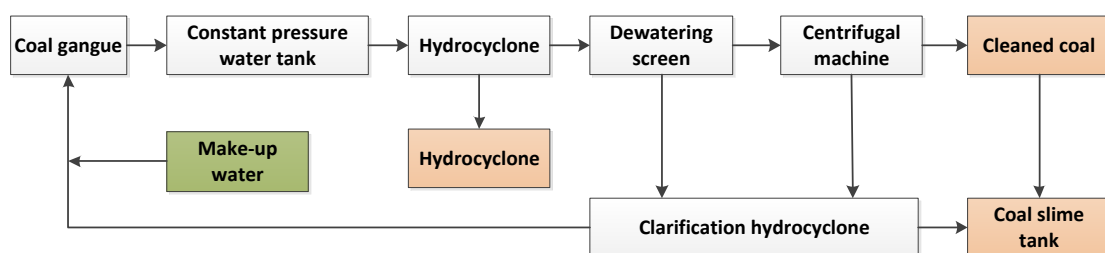


Fig.3-9 Process flow diagram of hydrocyclone separation process

#### b) Power generation

The coal gangue with the heat value between 6,270~12,550kJ/kg can be used as the fuel of the nearby fluidized bed boiler without washing, and the generated heat not only can be used for power generation ,but also for heat supply. This part of coal gangue is based on the washery rejects discharged by coal washing plant. Since 1990s,

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with the gradual replacement of bubble fluidized bed boiler by circulating fluidized bed (CFB) boiler, as well as with the development of smoke eliminating technology, the technology with the coal gangue for power generation become more and more mature.

Power generation with utilization of coal gangue is simple. Firstly, the mixture of coal gangue and inferior coal should be broken and sieved into powdered fuel with the grain diameter during 0mm~8mm. After that, it will be transported into the boiler via belt conveyor for burning in CFB. Fluidized bed combustion enables the coal gangue particles and coal granules to do boiling movement on furnace bottom depending on the high pressure draft sent into from the bed bottom, so as to form fluidized state in certain height. Finally, the smoke dust produced in combustion will be sent into the flue via dirt catcher, and the ashes produced in combustion will be pumped into ash yard after water cooling.

At present, coal gangue power plant generally will adopt electrostatic precipitator or bag type dust collector for dedusting, and the efficiency of dust collection can reach more than 99%. If mixing lime into gangue fuel is adopted to reach the direct desulfurating effect in the CFB boiler, the desulfurating rate can reach about 85%. As for slag after coal gangue combustion, its mass takes about 70% of the gangue quantity before combustion, the process like air splat cooling, airflow grinding, etc. should be adopted, and the obtained fly ash can be further utilized.

### **(4) Other application**

Coal gangue generally contains large amount of useful minerals, therefore, the minerals in coal gangue can be recovered to prepare chemical raw materials, which is the new way for coal gangue chemical utilization in recent years. It can be used for manufacturing aluminiferous products, including nanometer  $Al_2O_3$ , superfine alumina powder, crystallization of aluminum chloride and aluminiferous inorganic polymeric flocculant (IPF), etc., or used for chemical fertilizer production.

### **3.2.2 Technical approaches for fly ash comprehensive utilization**

The phase compositions of fly ash mainly are quartz, magnetite, mullite, vitreum,

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small amount of carbon, etc. The main physical and chemical properties of fly ash of power plant are shown in the tables. Combined with the physical and chemical properties of fly ash, its utilization channels are mainly concentrated in construction industry, agriculture and environmental protection aspects.

**Table.3-1 Physical properties of fly ash**

Physical property	Density /(kg/m <sup>3</sup> )	Loose dry capacity /(kg/m <sup>3</sup> )	Specific surface area /(m <sup>2</sup> /kg)	Porosity /%
Fluctuation range	2~2.3	550~800	270~350	60~75

**Table.3-2 Chemical components of fly ash %**

Item	Loss on ignition	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	R <sub>2</sub> O	SO <sub>3</sub>
content/%	3~20	43~56	4~10	20~35	1.5~0.5	0.6~2.0	1.0~2.5	0.3~1.5

### (1) Construction industry

The additional value of fly ash as construction materials is low, but due to the large utilization quantity, it is still an important aspect for fly ash utilization. The main technical approaches includes producing fly ash concrete, fly ash cement, fly ash brick, wall material and being used for construction backfill, etc.

#### a) Concrete additive

Fly ash used as concrete additive mainly utilizes its pozzolanic activity, so as to increase the intensity of the concrete. Most of the fly ash granules are spherical vitreous, the surface is smooth and compact, and it can improve the concrete workability and reduce water consumption via adding into concrete. Its subparticles are filled in the voids and pores, which can improve the concrete pore structure and increase compactness. In addition, fly ash also can reduce the hydration heat, and restrain concrete alkali-aggregate reaction.

#### b) Cement ingredients

The general cements are six major series like Portland cement, ordinary Portland cement, Portland-pozzolana cement, Portland fly-ash cement, complex Portland cement, etc. Portland fly-ash cement is levigated and produced by Portland cement clinker and 20%~ 40% of fly ash as well as proper amount of gypsum. Compared

with ordinary Portland cement, Portland fly-ash cement has advantages like low early strength, rapid increase of later phase strength, good crack resistance, good workability, coagulation time dilation, low hydration heat, good sulfate corrosion resistance, etc. Moreover, the specific area of fly ash is small, showing vitric ball shape. Therefore, the cement demand is less. The mortar or concrete mixed by it has good mobility, and is convenient for irrigating; especially suitable for large volume concrete construction.

Due to the  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  contained in fly ash, it can replace part of clay as the cement raw material to fire cement clinker. The mixing volume of the fly ash as cement raw material depends on the structure and its chemical compositions of the fuel firing cement. If coal is used to calcine clinker, the mixing volume of fly ash is about 4%. If oil is used to calcine clinker, the mixing volume of fly ash can reach 8%. Adding fly ash into cement production is a kind of utilization method with high additional value, it can save fuel, increase output, improve cement properties, decrease production cost, and increase the benefits of cement production enterprises.

### **c) Fly ash brick**

Fly ash brick mainly are two types of vitrified brick and steam-cured brick. Both of them have realized with industrialization production in industry, and are important ways to comprehensively use fly ash at present stage. The feature of vitrified brick is non-use of cement, and the adhesives are the raw materials like clay, shale, bentonite, etc. Sintering products has high strength with evenly distributed internal strength. Compared with clay vitrified brick, it has the advantages like light weight, high strength, good heat preservation and thermal isolation properties, as well as strong Freeze-thaw resistance, good durability, difficult pulverization, etc., more importantly its cost is low and is convenient for promotion.

The fly ash takes about 65% in the steam-cured brick. In addition, proper amount of aggregate quick lime and gypsum are mixed into it to firing to be brick after blank preparation, compression molding, code blank static stop, ordinary pressure or high pressure steam curing. The specification and dimension of the brick is (240 × 115 × 53) mm, which is completely same as the common solid clay brick, therefore, steam fly ash brick can be used to replace the solid clay brick.



#### **d) Wall product**

new-type wall materials, including corrugate glazed roof tile, suspended ceiling and heat insulation plate can be produced by taking fly ash as the main material, and mixing with components like clay, industrial waste residue, conditioner, etc. The production process is simple with large utilization quantity, and it saves clay and fuel.

#### **e) Filling materials**

In project construction, fly ash is used to replace the conventional sand, soil or other construction materials as the filling material, and compaction process is adopted to enable the backfill to have qualified compactness. Fly ash can be widely applied in repair and backfill material, grouting material of high grade road dam, roadbed and road surface, dam foundation construction of water conservancy project and other backfill projects (gully, subsidence area and underground goaf backfill).

### **(2) Environmental protection**

On aspect of environmental protection, it is mainly used for waste water and waste gas treatment based on the adsorption properties and specific components of fly ash. For example, the flocculating agents such as polymeric aluminium, aluminum sulfate, etc. produced with utilization of fly ash possess the features of low cost and high efficiency on aspect of waste water treatment.

Fly ash is a kind of porosity loose solid aggregation, which contains spongy and spherical fine particles composed by  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{Fe}_2\text{O}_3$ , etc. The average geometry internal diameter is  $40\mu\text{m}$ . The specific surface area is large, generally between  $2700\sim 3500\text{cm}^2/\text{g}$ , and it has strong adsorption capacity. Therefore, the property of fly ash alkalescence (PH value is between 9~11) is utilized to neutralize the acid in the waste water, and to carry out acid industrial waste water treatment. At present, as a cheap adsorbent, the absorption efficiency of fly ash is good in deodorization, removing SS, heavy metal ion and other toxic substance in printing and dyeing wastewater.

### **(3) Agriculture**

The application of fly ash in agriculture has the features of small investment, large use

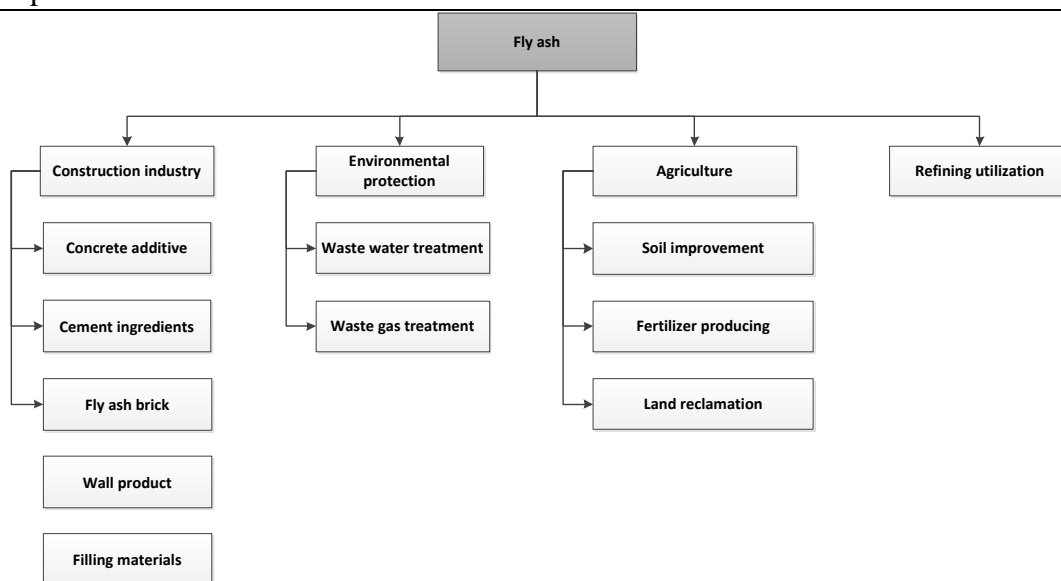
volume, etc. Its main utilization technologies are soil improvement, fertilizer producing, land reclamation and field returning, etc.

Fly ash has the properties of decompaction with porosities and good gas permeability. It can improve the soil slope structure via adding it into soil, increase gas and water permeability, increase ground temperature, and shrink expansion rate, especially has good effect to improve the clayey soil. Fly ash contains necessary nutrient elements like calcium, magnesium, etc. and the microelements beneficial for the growth of crops, including B, Mn, MO, Zn, etc. Central Research Institute of Electric Power Industry of Japan developed a new fertilizer with the utilization of fly ash, which has been used in planting cabbage and rice on trial. The rice yield increase rate is 17%~75%, and the oilseed rape yield increase rate is 130%~229%.

#### **(4) Refining utilization**

In recent years, the high additional value utilization of fly ash has become a focused issue. Many useful substances contained in fly ash can be recycled, including some rare metals.  $Al_2O_3$  content in fly ash generally can reach 20%~35%, and about 50% in maximum, which can replace bauxite to become a kind of very good aluminium oxide resource. Existing research mainly adopts following three methods, including sintering process, acid process and alkaline process. The main products include aluminium oxide. The residue can be used to co-produce cement, but the large scale production failed due to the causes on many aspects.

Non-burned coal separated from fly ash can be used as fuel or as the substitutes of carbon black and active carbon. In addition, the fly ash contains floating beads and sinking beads, due to the good mechanical property, chemical stability and insulating property, they can be used as cheap filling material. After being treated, the sinking beads can partially replace the conventional rubber filling materials, such as light carbon black, white carbon black, light calcium carbonate, etc., which are applied in many aspects like low density oil shaft cement, refractory brick, insulation cap, etc.



**Fig.3-10 Technical approaches for fly ash comprehensive utilization**

### 3.2.3 Comprehensive benefits of coal gangue utilization

The comprehensive utilization of coal gangues and fly ash helps the coal mine enterprises combine resource utilization with enterprise development and pollution abatement, and realize the unity of economic benefits, environmental benefits and social benefits.

#### (1) Economic benefits

The most direct benefit for the comprehensive utilization of coal gangue and fly ash is the economic benefit of an enterprise. Sintered brick production and cement manufacture, with low technical requirements and simple technological operation, are two key ways of gangue building materials utilization, which can save large amounts of clay and limestone resources as well as certain coal resources, and meanwhile can meet the requirements of rapidly developing infrastructure for building materials, bringing favorable economic benefits. The technology of fly ash cement production is mature, and the direct income of one-ton ash utilization is RMB100-150. The development of cement production by fly ash is promising. Large amounts of fly ashes are used in road building and backfilling and road building with fly ash can save cost RMB3 per square meter and RMB15-50 per one ton of fly ashes.

#### (2) Environmental benefits

Due to the increasing coal exploitation quantity, a large number of accumulations of coal gangue impacts ecological environments of mining area negatively. The coal

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gangue comprehensive utilization not only relieves the land occupation and secondary pollutions to ecological environments, but also eases the pollution to air and underground water in the mining area. Large amounts of raw coal consuming by world's power generation and cogeneration discharge coal ashes that threaten ecological environments seriously every year. Fly ashes raising dusts easily, with low water content and fine particles, are the source of suspended particles, which lead to regional air pollution and endanger human health. The resource utilization of fly ash can reduce damages to ecological environments and non-renewable resources, and recover the virtuous circle of ecological system to a larger degree.

### **(3) Social benefits**

The resource utilization of coal gangue and fly ash can realize resource comprehensive utilization, and comply with the social objective of resource conservation. Therefore, it is of great significance to develop the circular economy and promote sustainable developments of the national economy. The comprehensive utilization of coal gangue and fly ash is one important part of environmental protection industry, which can drive the development of relevant industries. In addition, as the new industry in mining areas, if the fly ash industry can form the trend of scale development, grouping management and industrialization development, it will create more employment opportunities.

#### **3.2.4 Challenges for APEC developing economies on coal gangue comprehensive utilization**

Although the comprehensive utilization of coal gangue and fly ash has multiple advantages, it has only formed scale in individual APEC economies, such as America, Japan and China. Most of the APEC developing economies which produce coals utilize coal gangue and fly ash limitedly with low utilization rate and only in building industry as filling materials. Problems of this aspect that the APEC developing economies facing mainly are:

1) Having weak awareness of comprehensive utilization and paying little attention to it. Although developed economies value comprehensive utilization of coal gangue and fly ash, most of the developing economies have weak awareness for this aspect. Only the Chinese government issues corresponding macro planning and instructive policies,

while governments and enterprises in other economies fail to emphasize coal gangue and fly ash utilization. These economies shall further strengthen the capital investment, government support and cooperation between government and enterprises.

2) The comprehensive utilization technology is to be improved. At present, the developed economies such as Japan, America and Canada have reached a level of refined classification for coal gangue and fly ash comprehensive utilization, while the developing economies mainly use it in the industries with low economic value added, which restricts the positivity of enterprises. The reason lays in that the coal gangue and fly ash utilization technology, especially the refining utilization technology of the developing economies needs more investment and improvement. Take the fly ash as an example, the advanced separation technology is especially important in fly ash comprehensive utilization. Fly ashes with different grain sizes have various chemical components and carbon contents and coal ashes generated by different coal qualities and thermal combustion technologies have different features. As the raw material of the downstream industry, it will surely lead to unstable raw material quality index, increasing difficulties of back-end production process adjustment, quality control and maintaining of constant finished product quality, and objectively restrict the stability of the scale utilization system market chain. However, most developing economies have not researched on this aspect deeply.

3) At present while the comprehensive utilization technology level of coal gangue and fly ash is improved, relevant policies and measures are required improved Take China as an example, Chinese government has issued the preferential policies for power generation by coal gangue, but conditions of which are strictly. The specific standard is mainly focusing on burning coal gangue with the usage amount no less than 60% of furnace fuels, and the lower heating value of furnace fuel as-fired basis shall be no more than 12550 KJ/kg (3000 kcal/kg). However, for the reason that the coal gangue have been pretreated before entering the furnace rather than directly putting into the furnace in some coal gangue power plants and the heat value of coal gangue after treatment reaches above 6000 kcal/kg, some coal gangue power generation technologies cannot be recognized as the coal gangue power generation project so as to influence the project approval and preferential policies enjoying. Meanwhile,

resource conditions and economic development levels are different between regions, so the regional unbalanced phenomenon in fly ash and coal gangue comprehensive utilization regions is severe. The comprehensive utilization rate is high in coastal areas where the economy is developed and technology level is high, and some areas even reach above 90%. Fly ashes and coal gangues there become rare resources for large market demands. Undeveloped areas, especially the traditional coal resource provinces, not only generate large amounts of coal ashes and gangues, but also have lower comprehensive utilization rate and excessive resource accumulation. However, at present, economic policies in China are under unified management by relevant ministries, and policies do not show sufficiently the regional difference.

### **3.3 Study on coal associated mineral comprehensive utilization mode**

Large amounts of metal and nonmetal minerals related to coals occur in the coal-bearing series, such as kaolin, bauxite and phosphorus ores. Besides, large amounts of organic minerals such as oil shale are existed. With the bulk mining of coals, large amounts of associated minerals are mined together. Most of them are piled as solid wastes rather than used effectively, and cause certain pollution to environments. With improvements of technology and in-depth researches on coal associated minerals, the comprehensive utilization of those minerals has been developed further.

Most of those coal associated minerals are deposited in the same geological gage of the coals. Some are the roof or base of the coals and some are the interlayer, so they generally are close to the coal layer. They are recovered while mining the coals, and are processed and used to avoid wastes and pollutions to environments, creating new economic growth. The coal associated minerals are of multiple benefits. The processing and utilization methods and benefits of kaolin and oil shale are analyzed as representatives.

#### **3.3.1 Technological approach for kaolin comprehensive utilization**

The coal-series kaolin is a kind of previous natural resource and important nonmetal mineral. The scientific name is kaolinite clay stone, which is a kind of hard kaolin accompanying the coal series. Due to the occurrence in parting and the roof or base of

coal layer, the kaolin can be mined together with the coals. The coal preparation plant technologies will add corresponding kaolin preparation technology rather than set kaolin preparation plant separately. The exploitation quantity in economies such as America, Russia and China is large.

The major utilization approach of coal mines for kaolin is to produce calcined kaolin products by the high quality coal-series kaolin after washing, preparation and purification (kaolinite content higher than 97% and iron oxide content less than or equaling to 0.5% ) through a series of manufacturing procedures, including coarse crushing, ultrafine grinding, drying, decentralizing and calcining. The calcined kaolin products are extensively applied to various industries such as paper making, rubber, paint, chemical industry, building materials, metallurgy, ceramics, glass, electric porcelain, and petroleum due to the powerful scattering force, favorable ink adsorption, high activity and whiteness, good electrical insulation property and thermal stability, high porosity and coverage rate, and small volume weight.

Key technologies of coal-series kaolin processing are ultrafine grinding and calcination. The process of ultrafine grinding, including dry method and wet method, is an important link to decide the kaolin quality. The coal-series kaolin ultrafine grinding belongs to the hard kaolin grinding (from 5~20mm to 40~80 $\mu$ m), most using dry method to directly grind the coal-series kaolinite into the ultrafine powder and entering calcination or other processes. The general fineness requirement shall be  $-10\mu\text{m} \geq 90\%$ . The grinding equipments mostly adopt high-speed impact grinder, vibration grinder, high-speed centrifugation grinder and dry stirred grinder. Although the functions, crushing scope, and energy consumption of various equipments are different, methods can be summarized into according to the crushing and grinding principles: a) Extrusion method: material crushed by pressure functioning on two operating surfaces. b) Impact method: crush the materials due to the impact force. The impact force is generated due to the impact of the moving operation body on materials, the materials moving at high speed impact on the fixed operating surface; the materials moving at high speed impacts each other; the operating body moving at high speed impacts on the suspended materials. c) Rubbing method: crush the materials by the shear force of the moving operating surface applied to materials when rubbing, or

by the shear force when materials rubbing. d) Splitting method: the materials are crushed due to the function of wedge-shaped operating body. The methods of various grinders to grind materials are different. Only one grinder will not use one method purely, but generally crush combining two or more methods. The extrusion method or impact method is used in coarse and secondary crushing processes during the existing coal-series kaolin ultrafine grinding process while the equipments in ultrafine grinding process mainly adopt rubbing method. In order to control the grain size distribution, especially the restriction of the largest grain size, the dry fine classification machine is required configuring.

Calcination is the key link of coal-series kaolin deep processing, and actually is one modification method of kaolin. Its major targets are: a) remove organic carbon and other impurity minerals to improve the whiteness; b) remove the water, hydroxyl of kaolin to improve the void volume, chemical reaction activity and physical and chemical performance of the calcined kaolin products so that they can meet various application requirements. The researches show that during calcination, at around 110°C, various absorbed water is discharged, at around 110~400°C, the interlayer water will be discharged; at around 500~600°C, remove large amounts of hydroxyl and the minerals turn to kaolin till 900~950°C, at 980°C Si-Al spinel start to form; at 1100°C mullite and cristobalite start to form, and at 1300~1400°C, all turn to mullite and cristobalite. The inversion of different phases decides the chemical and physical performance as well as application field of the calcined kaolin.

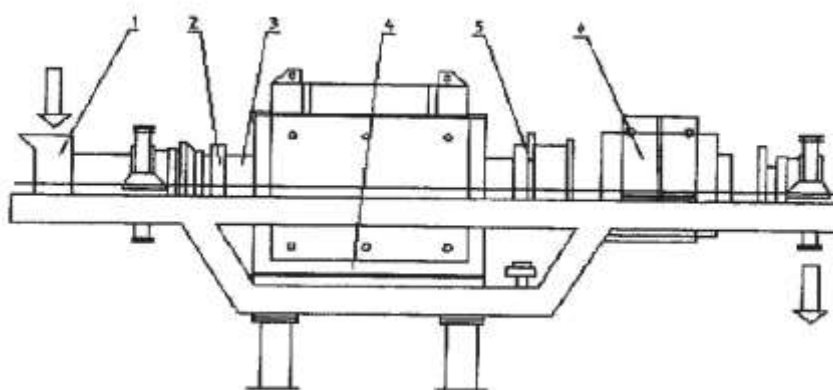
At present, the calcination equipments of common kaolin generally adopt directly-heated rotary kiln, Hankin kiln or Poz Jones cyclone furnace, which can adapt to the requirement of common kaolin for de-hydroxy reaction. Because the calcination process of coal-series kaolin also contains coal combustion reaction, the down-draft kiln and tunnel kiln cannot meet the requirement of such kaolin for calcination, and have obviously insufficiencies such as large labor intensity, long calcination time (the calcination period of down-draft kiln is about 7-10 days, and tunnel kiln is about 40 hours) and unstable product quality. In recent years, the domestic and foreign researchers and engineering technicians have also developed the following two characteristic calcination technologies.



### (1) Sleeve rotary kiln technology

It is the kaolin calcination technology developed by APV from Britain, which processing flow is shown in the figure: add the kaolin powders into the rotary casket placing obliquely so that the materials can move from the high end to the low end during the rotary of the casket. The heating medium (high-temperature flue gas) flows inversely and will be discharged from the high end after exchanging heat with the materials. The obvious feature of this technology is that the sleeve rotary kiln is adopted to separate the materials and flue gas (the materials are in the cylinder and the flue gas flows among the sleeves), and conduct heats (heating resisting metal) on the inner cylinder wall.

The sleeve rotary kiln separates the flue gas to make the coal-series kaolin contact with the hot air with higher oxygen content so as to promote the coal oxidation reaction and reduce the calcination time of coal-series kaolin to 4 hours. Although sometimes this technology is easy to lead to the short circuit outflow of the materials not calcinated, and the equipment is expensive (the kaolin calcination equipment with annual output of ten thousand ton is about RMB 20 Million), its automation degree is high and product quality is table.



**Fig.3-11 Sleeve Rotary Kiln**

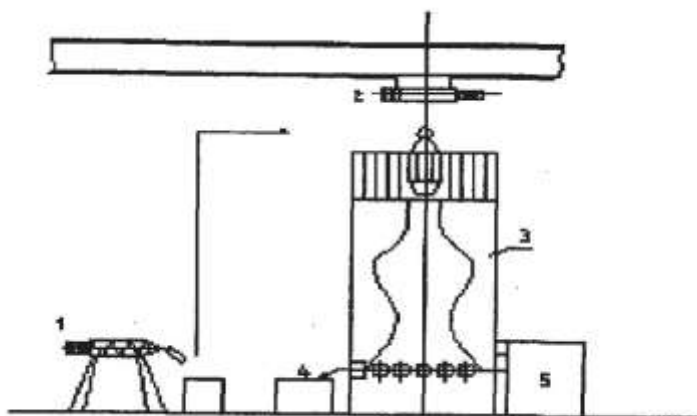
1-Feeding mechanism; 2-Tray; 3-Rotary cylinder; 4-Combistion furnace; 5-Chain driving wheel; 6-Colling box

### (2) Vertical kiln calcination technology

The processing flow is: feed the materials taking shape by adding water and additives into the crushed kaolin into the charge door on the roof. After the stages of drying, de-watering and calcination while the materials move downward, the materials are

discharged from the discharge door on the side of the bottom. The discharged materials shall enter the grinder after cooling to the secondary grinding, and the calcinated kaolin products are got after calcination. The time of coal-series kaolin calcinations by vertical kiln is 10-14 hours.

The technology uses coal as the fuel. The hot glue gas enters the kiln from the bottom and the waste gas is discharged from the roof. Its remarkable advantages are high heat use rate and simple operation. However, the coal dust content shall be controlled strictly. Besides, during the calcination, if the materials calcination bridging is caused due to over high temperature, the equipment shall be shut down and conduct crushing, shaping, calcination and secondary grinding for further improvement of the irrationality of crushing circular energy consumption.



**Figure 3-12 Vertical Kiln**

1-Extrusion former; 2-Crane bucket lifter; 3 Kiln body; 4-Discharging device; 5-Combustion chamber

### **3.3.2 Technological approach for oil shale utilization**

The oil shale (also known as kerogen shale) is a kind of high ash content sedimentary rock with combustible organic matters. The main difference between it and the coal is that its ash content is more than 40% and the main difference between it and the carbonaceous shale is that its oil content is larger than 3.5%. The shale oil can be obtained by carbonization of oil shale under low temperature. The shale oil is similar to the raw oil, and can be used to make gasoline, diesel or used as the fuel oil. Except the separated accumulation, oil shale is also the important coal associated mineral. Many economies in the world are actively developing the oil shale utilization technology. Brazil, Estonia and China have formed the industrial production scale.

The main utilization methods are to make shale oil and relevant products by separate screening and technologies such as carbonization, generate power or supply heat as fuels, and apply ashes to the production of building materials, cements and chemical fertilizers, etc.

### **(1) Manufacturing shale oil and relevant products**

The kerogen contained in the oil shale is not soluble in common organic solvent. Therefore, the kerogen can be transferred to the shale oil only by hot working. This method is called low-temperature carbonization, also known as low temperature pyrolysis or thermolysis. The basic principle of oil shale low-temperature carbonization is to heat the oil shale to certain temperature range (450~600°C) under the condition of air isolation to generate a series of physical and chemical reactions. The result of the reactions is to generate shale oil, coal gas and semi-coke. The shale oil is the major product which can not only be used as fuel oil directly, but also be transferred to gasoline, diesel, coal oil and paraffin. The coal gas is the byproduct and the semi-coke is used as waste residue.

The low-temperature carbonization of oil shale needs a complete set of production equipment, among which the major equipment is the gas retort and besides the supporting devices of oil, gas, sewage, semi-coke disposition are configured. The production process is generally: crush the raw shale from the ore, and send shale blocks (8 ~75mm) into the gas retort from the roof, which will move downward under fixed bed condition and be heated. Then the carbonization process is finished. The generated shale oil gas and coal gas are discharged from the top of the gas retort and pass through the subsequent devices to separate the shale oil and coal gas. The shale oil will be used as the product. The coal gas will return to the gas retort and be used circularly as the heat source. The surplus coal gas is used for other purposes, and the semi-coke (waste residue) will be discharged from the gas retort bottom.

The carbonization technologies are different, which can be divided into three classes by the heat supply methods of the gas retort: one is the gas retort technology with gas as the heat carrier, such as the Peter Rossi Kors technology in Brazil, Kiviter technology in Estonia and Fushun carbonization technology in China, which are the representative carbonization technologies in the world with mature technology and

long-term production and operation.. The other one is the retort technology with the solid as the heat carrier, such as the ATP technology in Canada. The Fushun carbonization technology developed by Fushun Mining Group, has reached the international advanced technology with features of stable operation, long operating period, low equipment failure rate, low level oil shale processing capacity, self heat support, simple operation and long-term stable operation, through over years' industrialized operation. After years of researches and improvement,

## **(2) Used as fuels**

There are mainly two methods of power generation by oil shale: one is to use oil shale directly as the boiler fuels, and generate steam for power generation; the other one is to conduct low-temperature carbonization to the oil shale, generate gas fuel and send to internal combustion engine for power generation. At present, the first method is mainly adopted. Initially, the oil shale is used as fuels of layer combustion boiler to generate electricity, which stops development due to low thermal efficiency and small single capacity. Later, the suspension combustion boilers are adopted, i.e. coal ash boiler, fluidized bed, and circulating fluidized bed combustion boiler.

The fluidized bed combustion boiler is a new kind of boiler between the layer combustion boiler and suspension combustion boiler. In 1960s, Germany firstly applied it to the oil shale power generation. Later it is promoted to the whole world, and becomes the major furnace extensively used in power generation by gangue, fault coal, sulphur coal, oil shale, lignite, industrial wastes and municipal wastes. For the power generation by oil shale combustion in circulating fluidized bed boiler, the oil shale entering the power plant is processed into 0~10mm particles after crushing and all used in combustion power generation. The ash carbon content after combustion is very low (1%~2%), while the combustion efficiency is over 98%, and the boiler thermal efficiency is over 88%. The ashes can be used to produce building materials fully.

### **3.3.3 Comprehensive benefits of coal associated mineral utilization**

Most of the coal measure strata not only have large amounts of coal resources, but also coexists or accompanies abundant nonmetal ores and some beneficial elements,

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which are non-renewable resources the same as the coal. Many coexisting and associated minerals have large reservoir and high grade, and are convenient for mining. There are favorable natural conditions for coal mine enterprises to develop the coexisting and associated minerals. The coexisting and associated minerals mining by coal mine shaft up and down production systems are the deep development for the former exploration resources, which can save exploration investment, infrastructure input and improve mine shaft utilization. The economic benefits and social benefits are of remarkable effect.

The coal-series calcined kaolin produced by coal-series kaolin resource deep processing is the high quality mineral raw materials replacing titanium white materials due to its favorable dispersity, coverage and ink absorbency, and has very important development and utilization value. The oil shale can be used as the substitution of major energy sources (coal, petroleum) nowadays, can ease energy crisis to certain degree and provide favorable guarantee for the regional energy security.

The coal associated minerals development expands the operation space of coal industry and promotes the sustainable development of the coal industry while providing more resources for the society and region. The development also drives developments of some relevant industries, create more employment opportunities. While proving commodities for the society, it also accumulates funds and contributes to the regional stability.

### **3.3.4 Challenges for APEC developing economies on coal associated mineral utilization**

At present, the demand for the nonmetal mineral products including the coal-series coexisting and associated mineral products in the whole world becomes larger, and its developments and utilization markets are promising. However, due to various reasons, the development and utilization degree in the APEC developing economies are still low, which mainly show in:

- 1) Insufficient cognition for the features of the coal associated minerals. For example, the coal-series kaolin has its own characteristics due to the formation causes different to that of the soft kaolin, such as certain carbon content, which directly impacts on the

processing and utilization of coal-series kaolin.

2) Low exploitation degree. In the past when exploiting the coal field, the work for distribution scope, reservoir of coexisting, associated kaolin, and oil shale were insufficient, and the planning and management had many problems.

3) Laggard theoretical research. The ultrafine grinding and fine classification technology are one of the most important deep processing technologies of coal coexisting and associated minerals. The key point lies in the equipment. The input of the developing economies into research is far less than that in the developed economies in the USA and Japan. The insufficient government policies and capital support lead to the relatively insufficient fund input for scientific research and developments of coal associated minerals.

4) Backward concepts with low development and utilization technology level. The operation and development mode in the mining area still focus on coal resources and lay less attention to the comprehensive utilization. Many areas have even not developed and used the coal associated minerals.

## 4. Assessment model for coal comprehensive utilization

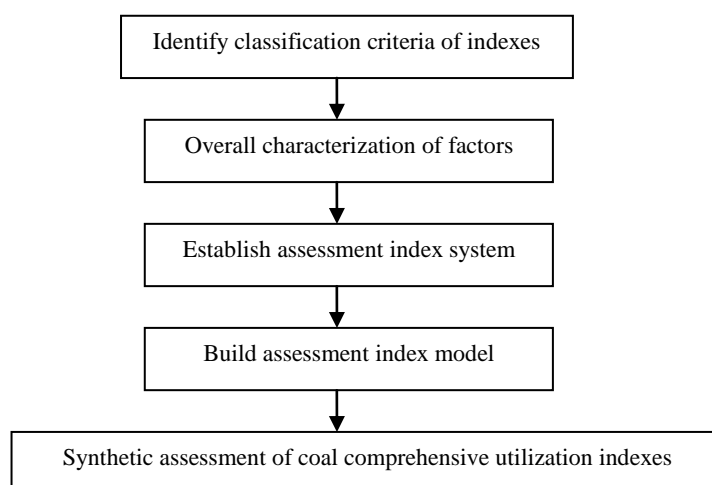
### 4.1 Principles for selecting indexes for coal comprehensive utilization assessment model

Selecting indexes for coal comprehensive utilization assessment model is a highly scientific, comprehensive, predicative, plan-based and practical effort that has to be performed in line with the following principles:

- a. Identity;
- b. Integrity;
- c. Comprehensiveness;
- d. Practicality;
- e. Strategy;
- f. Sustainability.

### 4.2 Evaluation process of coal comprehensive utilization assessment model

Analyzing, predicting and evaluating the indexes of the assessment model help identify which factors have the greatest effect on the comprehensive utilization of coal. The influencing factors of coal comprehensive utilization are generally evaluated in process shown in Fig.4-1.



**Fig.4-1 Evaluation flowchart of the comprehensive coal utilization index system**

**(1) Identify the classification criteria for comprehensive coal utilization indexes**

In terms of means of coal comprehensive utilization, the indexes to be evaluated can be categorized as technical indexes, economic indexes, environmental indexes, policy indexes and operation indexes. As these indexes vary in their degrees of effects on coal comprehensive utilization, classifying them will help identify the weight of the influencing factors of coal comprehensive utilization.

**(2) Overall characterization of indexes**

Changes of the indexes within the area of evaluation are assessed and tested by using certain evaluation criteria and methods. Information that is assessed and tested includes technical maturity, technical reliability, project efficiency transfer, technical maintenance, capital input, construction cost, operating cost, product price, inflation risks, and the degree and extent of eco environment changes. The key to the overall characterization of the factors is to select the required evaluation factors, acquire the correct state data of the evaluation factors, select the right evaluation criteria, and use a suitable mode for induction and translate qualitative data into qualitative language.

As far as projects associated with coal comprehensive utilization, mathematic models for evaluation can generally be divided into four categories: exponential models, probabilistic and statistical models, hierarchical and clustering models and index models. These four categories are not clearly separate from each other so can be used in combination while they are somewhat different.

**(3) Establish a comprehensive coal utilization assessment index system**

A comprehensive coal utilization evaluation index system is established such that it is science-based, relatively complete, simple, hierarchical, dynamic, relatively independent, operable and comparable, after characterizing the base data above for evaluating coal comprehensive utilization factors. To the extent that the completeness of the index system is not compromised, these data are also filtered to provide an index system that is both simple and effective.

**(4) Build a coal comprehensive utilization index assessment model**

Evaluating comprehensive coal utilization factors is an effort involving the assessment of a multi-goal, multilevel large complicated system, which can be



achieved by building a model for evaluating comprehensive coal utilization factors, using fuzzy comprehensive evaluation method (FCE), gray relational analysis (GRA), analytic hierarchy processing (AHP) and entropy coefficient method (ECM). After classified and quantified, the assessment indexes are assigned different weights. In general, greater weights are assigned to factors having greater effect on the coal comprehensive utilization applications.

#### **(5) Synthetic assessment of comprehensive coal utilization indexes**

After a model for evaluating comprehensive coal utilization indexes is built, the base data are calculated to identify the degree of effect on each individual subsystem and the overall degree of effect on the entire system, which enables synthetic assessment both qualitative and quantitative, of comprehensive coal utilization factors.

### **4.3 Structure of an index assessment system for coal comprehensive utilization**

#### **4.3.1 Principle for setting up an index evaluation system**

As the subsystems of the index assessment system are closely interactive and correlative and changes in any hierarchy, any element or any subsystem could cause qualitative changes in the entire system, to make sure that the true and correct system dynamics is identify, the indexes of the system built have to cover all the functional aspects of the system. However, such an index system will be exposed to excess number of indexes, difficulty in acquiring data and complicated evaluation calculations. Therefore, the following principles should be applied when we try to establish an assessment index system for coal comprehensive utilization factors:

#### **(1) Science-based**

It is crucial that the index system be science-based with clear index concepts and enough scientific connotations to address and represent the present and potential structure and functions of the compound system.

#### **(2) Relatively complete**

As an organic whole, the index system should be able to reflect and measure the main features and state of development of the object evaluated in a more comprehensive way.

**(3) Simple**

To the extent that the completeness is not compromised, indexes should be selected to provide a simple index system. Representative synthetic and major indexes should be selected where practically possible.

**(4) Relatively independent**

Indexes at the same levels should be able to address a factor of the object evaluated. Relatively independent indexes should be selected where practically possible to generate more accurate and scientific evaluation.

**(5) Operable**

Indexes should be selected to use existing statistical records where practically possible. Indexes selected should be measurable, comparable and quantifiable. In actual investigation, index data should be easily acquired by sorting statistical records, spot checks or typical surveys or directly from relevant departments (e.g. research institutes or technical departments).

**(6) Comparable**

Success of comparative studies on different evaluation objects largely depends on the comparability of statistical index measurements and the reliability of sources, which form an important part to be addressed in establishing an index assessment system of influencing factors.

In conclusion, when setting up and selecting indexes, it is important to make sure that the indexes are science-based, complete, simple, hierarchical, dynamic, independent and operable. Science-based, complete, hierarchical and dynamic play an important role in the theoretical research on the evaluation index system for comprehensive coal utilization factors, while simple, independent and operable help promote the application of the index system in practical evaluations.

#### **4.3.2 Hierarchy and content of the index assessment system**

As studies based on the coal comprehensive utilization assessment index system is an interaction and collaboration process among a number of social, economic, technical and natural factors, resultantly, the evaluation itself, therefore, is multi-goal and involves both economic and non-economic goals, both increase and structural optimization goals, and both efficiency and equality goals. For this complicated multi-goal complex, to measure its overall synthetic goal easily, some highly generic, scientific indexes of different hierarchies should be used to achieve these goals.

After the structural framework of the index assessment system for coal comprehensive utilization factors is determined, a series of base indexes and synthetic indexes will be needed to represent the evaluation criteria selected and the final evaluation goals to enable the establishment of an index system for assessment. Following the general goal and the basic principle for establishing an index assessment system, by reference to existing findings from studies on sustainable development index systems, a step-by-step recursion, and relatively complete synthetic evaluation system is developed with hierarchies and index details as shown in Fig.4-2.

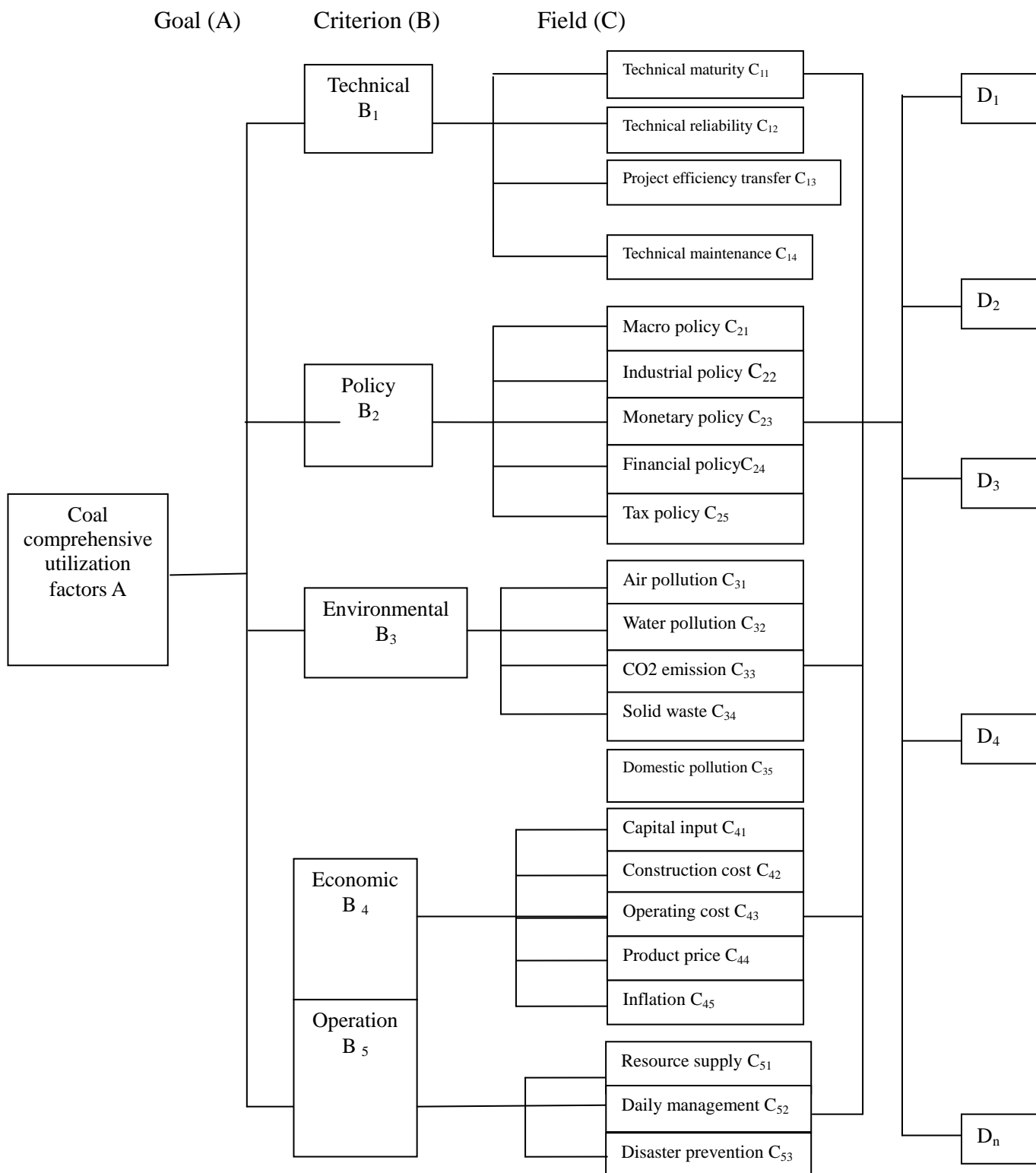


Fig.4-2 Comprehensive coal utilization evaluation index system

### 4.3.3 Select an index assessment model for coal comprehensive utilization

An index assessment system for comprehensive coal utilization is an evaluation effort involving a multi-goal, multilevel consideration large complicated system for which additive scoring, weighted scoring, fuzzy comprehensive evaluation, gray rational

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analysis, analytic hierarchy processing and entropy coefficient method are generally used. The former two are classic comprehensive evaluation processes while the latter four are modern mathematic comprehensive evaluation methods. The classic evaluation processes are easily performed and provide clear results, but often fail to reflect the real characteristics of the object evaluated when some systems are fuzzy due to unclear internal or external factors. To solve this problem, modern mathematic evaluation methods have been introduced. As the degree of impact of coal comprehensive utilization factors is a fuzzy concept that lacks clear external extension and appears to be complicated due to the rich connotations, it is impractical to derive realistic evaluation conclusions if classic evaluation methods are used. Modern mathematic methods, typically fuzzy mathematics, offer a scientific and effective means for us to solve this problem.

Currently, there are many ways of setting up weights used in multi-goal, multilevel synthetic evaluations, of which the mainstream method is analytic hierarchy processing. Over the past years, analytic hierarchy processing has been widely used in weighting. Other methods have also been used, but in a very limited area.

Analytic hierarchy processing (AHP) is a multi-goal planning method and the optimal technique developed by American operational expert T.L.Saaty that combines qualitative studies with quantitative analysis. First, it establishes an internally independent hierarchic structure representing the system concept of features, which decomposes the complicated system into a number of subsystems and groups them according to their degree of membership. Next, it identifies the relative importance of the subsystems at each hierarchy by pair-wise comparison of a certain feature. Finally, it determines the total order of the relative importance of the subsystems by using human judgments.

AHP is used to identify the weight of each index involved in evaluating the coal comprehensive utilization factors in the following steps:

(1) Identify the goal and assessment factor sets and establish their hierarchic structure (which was completed when establishing the index system).

(2) Structure a judgment matrix for pair-wise comparison at the same hierarchies:

Now, assume  $A$  is the goal,  $B_i$  is the assessment factor, ( $i=1,2, \dots, n$ ).  $B_{ij}$  is the importance value of  $B_i$  relative to  $B_j$ , ( $i=1,2, \dots, n$ ). Then the value of  $B_{ij}$  is derived from the table below. ...

According to the result of pair-wise comparison of the factors, the  $A—B$  judgment matrix  $P$  is derived.

$$P = \begin{pmatrix} B_{11} & B_{12} & \dots & B_{1n} \\ B_{21} & B_{22} & \dots & B_{2n} \\ \vdots & \vdots & & \vdots \\ B_{n1} & B_{n2} & \dots & B_{nn} \end{pmatrix}$$

where:  $B_{ij} > 0$ ,  $B_{ii} = 1$ ,  $B_{ij} = 1/B_{ji}$

**Table.4-1 Definition of AHP 1-9 scale**

Scale	Definition
1	The two elements are equally important
3	One element is slightly more important than the other
5	One element is significantly more important than the other
7	One element is highly more important than the other
9	One element is absolutely more important than the other
2, 4, 6, 8	Median of adjacent judgment values above

(3) Characteristic vector and maximum characteristic root  $\lambda_{\max}$  of the  $A—B$  judgment matrix  $P$

The characteristic vector is mainly derived using square root or sum-product method, the former of which is used herein.

$$\bar{w}_i = \sqrt[n]{\prod_{j=1}^n B_{ij}} \quad i, j = 1, 2, \dots, n$$

Vector  $\bar{W} = (\bar{w}_1, \bar{w}_2, \dots, \bar{w}_n)$  is normalized, i.e.

$$w_i = \bar{w}_i / \sum_{i=1}^n \bar{w}_i$$

Then, vector  $W = (w_1, w_2, \dots, w_n)$  is the characteristic vector to be obtained and also the weight vector.

Maximum characteristic root  $\lambda_{\max} = \sum_{i=1}^n \frac{(pw)_i}{nw_i} = \frac{1}{n} \sum_{i=1}^n \frac{(pw)_i}{w_i}$

where:  $(pw)_i$  is element  $i$  of vector  $pw$ .

(4) Consistency test

The characteristic vector so derived is the weight to be obtained. But whether the weights are properly allocated will have to be measured by consistency test on the judgment matrix. This is achieved using the following expression.

$$CR = C.I./R.I.$$

where:  $C.I. = \frac{1}{n-1}(\lambda_{\max} - n)$ , and the  $R.I.$  can be obtained by reference to relevant documents.

If  $CR < 0.1$ , then the judgment matrix is considered to have satisfactory consistency and the weight allocation from it is correct. If not, the matrix will have to be adjusted until satisfactory consistency is achieved.

It is need to note that like evaluation indexes, temporal and spatial changes also occur in index weights. Therefore, specific temporal and spatial factors will have to be considered when identifying index weights. Based on the many references available and the operational realities of comprehensive coal utilization projects in China, a project is feasible when the weight of index A is larger than 0.5, and the higher value of the weight will mean better feasibility of the project.

**4.3.4 Questionnaire on comprehensive coal utilization factors**

The importance levels of comprehensive coal utilization factor evaluation indexes are identified after consulting experts.

**Table 4-2 Questionnaire on comprehensive coal utilization factors**

Comparison of importance level		Pair-wise comparison scale (importance level)				
		Equally important	Slightly important	Significantly important	Highly important	Extremely important
Pair-wise index comparison evaluation comment						
Index A	[ ]	Index B				

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Technology (B <sub>1</sub> ) [ ]	Policy (B <sub>2</sub> )				
Technology (B <sub>1</sub> ) [ ]	Environmental (B <sub>3</sub> )				
Technology (B <sub>1</sub> ) [ ]	Economic (B <sub>4</sub> )				
Technology (B <sub>1</sub> ) [ ]	Operation (B <sub>5</sub> )				
Policy (B <sub>2</sub> ) [ ]	Environmental (B <sub>3</sub> )				
Policy (B <sub>2</sub> ) [ ]	Economic (B <sub>4</sub> )				
Policy (B <sub>2</sub> ) [ ]	Operation (B <sub>5</sub> )				
Environmental (B <sub>3</sub> ) [ ]	Economic (B <sub>4</sub> )				
Environmental (B <sub>3</sub> ) [ ]	Operation (B <sub>5</sub> )				
Economic (B <sub>4</sub> ) [ ]	Operation (B <sub>5</sub> )				
Index <b>B</b> [ ]	Index <b>C</b>				
Technical maturity(C <sub>11</sub> ) [ ]	Technical reliability (C <sub>12</sub> )				
Technical maturity(C <sub>11</sub> ) [ ]	Project efficiency transfer (C <sub>13</sub> )				
Technical maturity(C <sub>11</sub> ) [ ]	Technical maintenance (C <sub>14</sub> )				
Technical reliability (C <sub>12</sub> ) [ ]	Project efficiency transfer (C <sub>13</sub> )				
Technical reliability (C <sub>12</sub> ) [ ]	Technical maintenance (C <sub>14</sub> )				
Project efficiency transfer (C <sub>13</sub> ) [ ]	Technical maintenance (C <sub>14</sub> )				
Macro policy (C <sub>21</sub> ) [ ]	Industrial policy (C <sub>22</sub> )				
Macro policy (C <sub>21</sub> ) [ ]	Monetary policy (C <sub>23</sub> )				
Macro policy (C <sub>21</sub> ) [ ]	Financial policy (C <sub>24</sub> )				
Macro policy (C <sub>21</sub> ) [ ]	Tax policy (C <sub>25</sub> )				
Industrial policy (C <sub>22</sub> ) [ ]	Monetary policy (C <sub>23</sub> )				
Industrial policy (C <sub>22</sub> ) [ ]	Financial policy (C <sub>24</sub> )				
Industrial policy (C <sub>22</sub> ) [ ]	Tax policy (C <sub>25</sub> )				
Monetary policy (C <sub>23</sub> ) [ ]	Financial policy (C <sub>24</sub> )				
Monetary policy (C <sub>23</sub> ) [ ]	Tax policy (C <sub>25</sub> )				
Financial policy (C <sub>24</sub> ) [ ]	Tax policy (C <sub>25</sub> )				
Air pollution (C <sub>31</sub> ) [ ]	Water pollution (C <sub>32</sub> )				
Air pollution (C <sub>31</sub> ) [ ]	CO <sub>2</sub> emission(C <sub>33</sub> )				
Air pollution (C <sub>31</sub> ) [ ]	Solid waste (C <sub>34</sub> )				
Air pollution (C <sub>31</sub> ) [ ]	Domestic pollution (C <sub>35</sub> )				
Water pollution (C <sub>32</sub> ) [ ]	CO <sub>2</sub> emission(C <sub>33</sub> )				
Water pollution (C <sub>32</sub> ) [ ]	Solid waste (C <sub>34</sub> )				
Water pollution (C <sub>32</sub> ) [ ]	Domestic pollution (C <sub>35</sub> )				
CO <sub>2</sub> emission(C <sub>33</sub> ) [ ]	Solid waste (C <sub>34</sub> )				
CO <sub>2</sub> emission(C <sub>33</sub> ) [ ]	Domestic pollution (C <sub>35</sub> )				
Solid waste (C <sub>34</sub> ) [ ]	Domestic pollution (C <sub>35</sub> )				



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Capital input (C <sub>41</sub> )	[ ]	Construction cost(C <sub>42</sub> )					
Capital input (C <sub>41</sub> )	[ ]	Operating cost (C <sub>43</sub> )					
Capital input (C <sub>41</sub> )	[ ]	Product price (C <sub>44</sub> )					
Capital input (C <sub>41</sub> )	[ ]	Inflation (C <sub>45</sub> )					
Construction cost(C <sub>42</sub> )	[ ]	Operating cost (C <sub>43</sub> )					
Construction cost(C <sub>42</sub> )	[ ]	Product price (C <sub>44</sub> )					
Construction cost(C <sub>42</sub> )	[ ]	Inflation (C <sub>45</sub> )					
Operating cost (C <sub>43</sub> )	[ ]	Product price (C <sub>44</sub> )					
Operating cost (C <sub>43</sub> )	[ ]	Inflation (C <sub>45</sub> )					
Product price (C <sub>44</sub> )	[ ]	Inflation (C <sub>45</sub> )					
Resource supply (C <sub>51</sub> )	[ ]	Daily management (C <sub>52</sub> )					
Resource supply (C <sub>51</sub> )	[ ]	Disaster prevention (C <sub>53</sub> )					
Daily management (C <sub>52</sub> )	[ ]	Disaster prevention (C <sub>53</sub> )					

The elements are scored by experts using the 1-9 scale method. The lower elements are pair-wise compared, taking the upper elements as the criteria before the judgment matrix is obtained for each hierarchy.

In this way, after summarizing the principles above, parameters for the coal comprehensive utilization index assessment system are designed. Those parameters not available or available but with only qualitative indexes are directly incorporated into the model by using AHP. Available realistic data are normalized to eliminate dimensions of different data and incorporated into the model. The scores of different ways of coal comprehensive utilization are calculated with the model to achieve the result and objective of the evaluation by choosing the appropriate way of utilization according scores.

#### 4.4 Case analysis

Two means of coal comprehensive utilization – CMM (power generation) and CMM purification – are studied with 40% concentration coal mine methane. Parameters involved in the coal comprehensive utilization assessment model are sorted and normalized before they are incorporated into the model, calculated and compared.

##### (1) Construction of a CMM power plant (D<sub>1</sub>)

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Investment for a CMM power plant: RMB3000~4000/kW, guaranteed continuous rating of generator units: 400kW, annual service hours: 300d min, annual power generation capacity per generator unit: 3000000kWh (consuming 1000000m<sup>3</sup>/a of pure methane), annual revenue from power generation per generator unit: RMB 1200000 (at the rate of RMB0.4 /kWh) , annual power generation cost per generator unit including oil consumption, payroll, equipment maintenance and equipment depreciation: RMB0.10/kWh, annual operating cost per generator unit = RMB0.10/kWh×3000000kWh=RMB300000. At the rate of RMB0.5 per cubic meter of pure methane, the gas supply cost is RMB50000/a. The annual revenue per generator unit = annual power generation revenue – annual total cost = 1200000 – 300000 – 500000 = RMB400000. The power generation profit per cubic meter of pure methane is RMB0.4/m<sup>3</sup>.

**(2) Construction of a CMM purification project (D<sub>2</sub>)**

After deoxidization, purification, separation, compression and refinement, CMM can be made into CNG which can be delivered reliably at lower cost in specially designed cylinder cars. This saves a lot of investment and is more flexible than underground pipe delivery. CNG is characterized by high storage and modest land occupation with storage efficiency 250 times higher than conventional low-pressure gas tanks. CNG production is safer. The entire CMM-to-CNG production uses proven process and devices with extensive industrial application. For a CNG plant with designed annual process capacity of 20000000m<sup>3</sup> pure methane, the investment cost is approximately RMB22 million. At the wellhead rate of RMB0.5 per cubic meter of pure methane, the unit processing cost is RMB0.67/m<sup>3</sup> and the total cost is RMB1.24/m<sup>3</sup>. At the factory rate of RMB2/m<sup>3</sup>, the profit per cubic meter is RMB0.76/m<sup>3</sup>. Besides, the transport cost per 100km for compressed CBM is approximately RMB0.4/m<sup>3</sup>, compared to the approximately RMB0.07/m<sup>3</sup> for liquefied CBM.

After available data are measured, they are normalized and qualitative indexes are reviewed. After synthetic evaluation, the following judgment matrix is obtained.

**Table.4-3 Judgment matrix**

A	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	B <sub>5</sub>
B <sub>1</sub>	1	5	5	7

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B <sub>2</sub>		1	3	5
B <sub>3</sub>			1	5
B <sub>5</sub>				1

B <sub>1</sub>	C <sub>11</sub>	C <sub>12</sub>	C <sub>13</sub>	C <sub>14</sub>
C <sub>11</sub>	1	3	1	5
C <sub>12</sub>		1	1	3
C <sub>13</sub>			1	5
C <sub>14</sub>				1

B <sub>2</sub>	C <sub>21</sub>	C <sub>22</sub>	C <sub>23</sub>	C <sub>24</sub>	C <sub>25</sub>
C <sub>21</sub>	1	3	3	3	3
C <sub>22</sub>		1	5	3	5
C <sub>23</sub>			1	1	3
C <sub>24</sub>				1	3
C <sub>25</sub>					1

B <sub>3</sub>	C <sub>31</sub>	C <sub>32</sub>	C <sub>33</sub>	C <sub>34</sub>	C <sub>35</sub>
C <sub>31</sub>	1	1	3	5	5
C <sub>32</sub>		1	3	5	5
C <sub>33</sub>			1	5	5
C <sub>34</sub>				1	3
C <sub>35</sub>					1

B <sub>5</sub>	C <sub>51</sub>	C <sub>52</sub>	C <sub>53</sub>
C <sub>51</sub>	1	5	3
C <sub>52</sub>		1	1
C <sub>53</sub>			1

Based on the judgment matrix orders, the average random consistency index R.I. is derived from the following table.

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Table.4-4 Average random consistency index R.I.

<b>Matrix order</b>	1	2	3	4	5	6	7	8
<b>R.I.</b>	0	0	0.52	0.89	1.12	1.26	1.36	1.41
<b>Matrix order</b>	9	10	11	12	13	14	15	
<b>R.I.</b>	1.46	1.49	1.52	1.54	1.56	1.58	1.59	

The calculation results are shown in the table below.

Table.4-5 Hierarchical calculation weight vectors with test results

A	Single ordering weight
B <sub>1</sub>	0.4529
B <sub>2</sub>	0.2597
B <sub>3</sub>	0.4175
B <sub>5</sub>	0.2089

B <sub>1</sub>	Single ordering weight
C <sub>11</sub>	0.4529
C <sub>12</sub>	0.2597
C <sub>13</sub>	0.4175
C <sub>14</sub>	0.2089

B <sub>2</sub>	Single ordering weight
C <sub>21</sub>	0.2286
C <sub>22</sub>	0.2254
C <sub>23</sub>	0.2065
C <sub>24</sub>	0.2012
C <sub>25</sub>	0.2174

B <sub>3</sub>	Single ordering weight
C <sub>31</sub>	0.5845

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C <sub>32</sub>	0.5643
C <sub>33</sub>	0.5799
C <sub>34</sub>	0.5450
C <sub>35</sub>	0.5491

B <sub>4</sub>	Single ordering weight
C <sub>41</sub>	0.7487
C <sub>42</sub>	0.7149
C <sub>43</sub>	0.7843
C <sub>44</sub>	0.7450
C <sub>45</sub>	0.7934

B <sub>5</sub>	Single ordering weight
C <sub>51</sub>	0.3146
C <sub>52</sub>	0.2987
C <sub>53</sub>	0.3208

**Table.4-6 Total ordering of hierarchy C**

C <sub>11</sub>	0.1072	C <sub>33</sub>	0.3986
C <sub>12</sub>	0.0953	C <sub>34</sub>	0.3654
C <sub>13</sub>	0.1054	C <sub>35</sub>	0.3452
C <sub>14</sub>	0.0743	C <sub>41</sub>	0.4753
C <sub>21</sub>	0.0543	C <sub>42</sub>	0.4363
C <sub>22</sub>	0.0534	C <sub>43</sub>	0.4216
C <sub>23</sub>	0.0486	C <sub>44</sub>	0.4786
C <sub>24</sub>	0.0399	C <sub>45</sub>	0.4374
C <sub>25</sub>	0.0453	C <sub>51</sub>	0.0426
C <sub>31</sub>	0.3864	C <sub>52</sub>	0.0411
C <sub>32</sub>	0.3641	C <sub>53</sub>	0.0487

**Table.4-7 Total ordering of hierarchy D**

D <sub>1</sub>	D <sub>2</sub>
0.5621	0.5593
C.R.=0.0121	C.R.=0.0128

In the total ordering, C.R.<0.1, it is suggested that the overall consistency of the judgment matrix is acceptable. The two ways of utilization have similar values. According to the degree of membership principle, this means that the CMM power generation project is of a higher degree given the 40% methane concentration.

## 5. Conclusion and Suggestions

The problems of high consumption, pollution, emissions and low efficiency during coal processing exist in most of APEC economies. In recent years, APEC indicated at all previous leaders economic conference and energy work conferences that the key point to guarantee energy safety, economic growth and tackle climate change is the improvement of energy efficiency. APEC economies have issued a series of preferential and encouraging policies to improve energy efficiency, which create favourable development environment for coal comprehensive utilization. On the other hand, achieved breakthroughs on coal comprehensive utilization and rapid developments of diversified industries, such as CBM, coal gangue, fly ash and various coal associated minerals, create favourable market conditions for coal comprehensive utilization.

Therefore, the proper selection of the utilization mode in accordance with the specific situations of each economy and resources of enterprises on the one hand can improve coal utilization efficiency and realize waste cyclic utilization, energy conservation and emission reduction; and on the other hand can obtain obvious economic benefit and social benefit. It is necessary to promote the reasonable utilization mode in APEC areas, especially in the developing economies.

At present, the development situation of coal comprehensive utilization in APEC developing economies is unsatisfactory, and has a large gap compared with that in the developed economies. Rapid and healthy developments of coal comprehensive utilization are restricted to weak awareness of comprehensive utilization, mismatched industrial layout and resource distribution, low market awareness, drawbacks of current policies in links of stipulation, adjustment and implementation and insufficient of the basic theoretical research and capital input of key technology.

Therefore, the suggestions are proposed as follows:

### 1) Strengthen policy guidance and financial support

The government shall strengthen the policy guidance for coal comprehensive utilization, and improve the awareness of coal comprehensive utilization among entire society. The government shall enhance and strengthen the guidance and support of

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central financial incentive fund and construction investment, comprehensively consider such factors as utilization cost and market selling price, formulate the economical preferential policies such as tax deduction and exemption, sufficiently mobilize the positivity of enterprises and promote the implementation of coal comprehensive utilization fundamentally.

### 2) Optimize industrial layout, and adjust the energy structure

Reasonably adjust the industrial layout, optimize capacity structure, accelerate formulating the industrial layout planning of the system, expand the energy comprehensive utilization scale, lead the coal mining areas to greatly develop the comprehensive utilization industries which feature advanced technology, high utilization rate, environmental protection and energy saving, and are in favor of the sustainable development of the social economy, and improve comprehensive utilization technology level. Prioritize the projects with high economic value added such as CMM power generation, coal gangue power generation, brick and cement manufacturing by fly ash, plan, construct and reform the mining area as required by cyclic economy, and form the industrial chain of resource high efficient cyclic utilization to strive to improve the energy utilization efficiency.

### 3) Play the role of market mechanism

Play the role of market mechanism, complete investment method, and strive to promote the comprehensive utilization of coals. Increase the capital input in coal comprehensive utilization by multiple channels, and form the mechanism for comprehensive utilization products and technology innovation facing the market. In addition that the central government gives the necessary support continuously to the enterprises for comprehensive utilization in terms of policies and funds, the enterprises themselves shall adapt to the requirements of market economy development as soon as possible, manufacture market demand-oriented products, update the varieties and specifications with the market changes, and step into the benign track of enterprise-oriented operation as fast as they can.

### 4) Focus on fundamental research and promote technological breakthrough and international cooperation

Accelerate the research and application of the technology, enhance the construction of



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innovative platform, and further strengthen the support for the basic theoretical research of coal comprehensive utilization. Develop and promote the practical technologies, increase the overall technology level of coal comprehensive utilization, enhance the national fund input in the scientific research, organize the technological breakthroughs of key technologies and key products, actively promote the demonstration projects with successful experiences, improve product quality and product added value, and improve overall technology level and economic benefits. Insist on combining the independent development and technology introduction, introduce key advanced technologies and equipments selectively, accelerate new technology development and product update speed, and strengthen the independent innovative capacity. Expand the international cooperation and exchange in the field of coal comprehensive utilization and energy improvement, introduce and absorb the advanced technology and research measures, and develop cooperative research and joint project development.