# Chapter 7
# Coal-Derived Liquid Fuels

**Liu Pei, Ma Linwei, Liu Guangjian, Pan Lingyin, and Li Zheng**

**Abstract** In this chapter, after a brief introduction, we first suggest the potential of resource supplies for coal-derived fuels based on a review of coal production, utilization, and supply constraints in China. The technological development of coal-derived fuels is the main focus of this chapter. We first present the current status of the development of four technology pathways—direct and indirect coal liquefaction, coal-derived methanol, and coal-derived dimethyl ether—and compare the technical performance of their conversion processes based on published data. Then, we conduct a well-to-tank analysis of their technical performance considering three routes in the supply chain design, and we discuss the influence of carbon tax. A six-dimension method is also applied to compare the advantages and disadvantages of the four technology pathways. Finally, by identifying the barriers and future potential of these technology pathways, we propose policy suggestions for their future development.

**Keywords** Coal • Coal-derived liquid fuel • Coal liquefaction • Methanol • Dimethyl ether

## 7.1 Introduction

China's energy supply has been largely characterized by the dominance of coal based on domestic production, and this also represented the country's main energy-development strategy. In recent years, however, China's dependency on oil imports has rapidly grown, and the international price of oil has remained high. Thus, it has become increasingly necessary for China to develop its coal industry to produce

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alternatives to oil-based gasoline and diesel, using instead coal-derived liquid fuels, for which there are relatively rich and inexpensive resources. In addition, coal-derived liquid fuels have gained attention as an important technology toward helping to assure national energy security. At the same time, though, the development of coal-derived liquid fuels is highly controversial because of the low energy efficiency, high $CO_2$ emissions, and high water consumption; this is therefore a problematic area for the national energy strategy. Before coal-derived liquid fuels are fully developed, the whole of society needs to arrive at a coherent understanding of their future and the various issues involved.

This chapter assesses the technological development of coal-derived liquid fuels from a variety of aspects. Through data collection and analysis, we attempt to offer a comprehensive assessment and formulate preliminary policy suggestions.

Regarding chapter content, Sect. 7.2 summarizes the present situation of coal use and development in China; it considers the availability of coal resources and analyzes potential issues regarding the resource supply of coal-derived liquid fuels. Section 7.3 is a comprehensive evaluation of various coal-derived liquid fuels. The current state of coal-derived liquid fuel technologies is presented, including those of direct coal-to-liquid, indirect coal-to-liquid, coal-derived methanol, and coal-derived dimethyl ether (DME). The technical, economic, and environmental performances of these processes are compared. In addition, a well-to-tank (WTT) analysis and comparison of energy consumption and emissions is made; the effect of a carbon tax on coal-derived liquid fuels is examined. Further, a preliminary analysis is made on the major advantages and disadvantages of several coal-derived liquid fuels by means of a six-dimension analysis method. Section 7.4 presents a development policy analysis of coal-derived liquid fuels in China. The current situation, present obstacles, and future potential of coal-derived liquid fuels are evaluated, and development policy suggestions are provided. Section 7.5 offers a preliminary conclusion and recommendations on research analysis and policy implications.

## 7.2 Potential of Resource Supply for Coal-Derived Liquid Fuels

Despite its rich coal resources, the sustainable coal supply in China is severely constrained by mining security, water resources, ecosystem preservation, and transportation capacity. Under these restrictions, the coal for liquid fuel production is affected by the demand for coal by other sectors and industries. This chapter therefore describes the present situation regarding coal resources, production, transportation, importation, and use to summarize coal development in China. Subsequently, a preliminary analysis on potential coal resources for liquid fuel production will be made.

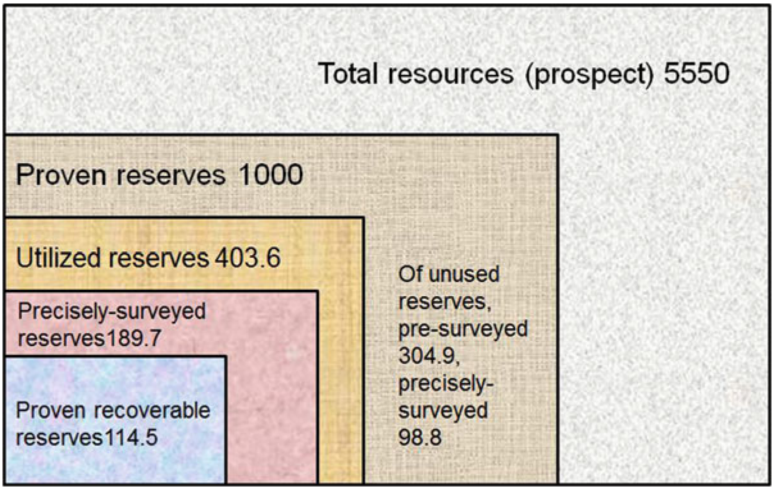

**Fig. 7.1** Coal resources and coal reserves in China (2010)

## 7.2.1 *Coal Production and Use*

### 7.2.1.1 Coal Resources

Compared with the country's oil and natural gas resources, China's coal resources are relatively rich. According to data from BP (2010), China's proven recoverable coal resources accounted for 13.9 % of the world total in 2009, whereas its oil and natural gas resources accounted for only 1.3 and 1.1 %, respectively.

In general terms, China has great potential for increasing its coal resources (Fig. 7.1). According to the coal resource assessment in 1999 (Mao 1999), China's total coal resources (prospect resources) amount to 5,550 billion tons, and the country ranks first in the world for this commodity. The total proven reserves are about 1,000 billion tons (Pu 2010), of which the utilized reserves are 403.6 billion tons, precisely surveyed utilized reserves are 189.7 billion tons, and proven recoverable reserves are 114.5 billion tons. Of the unused reserves, the estimated reserves are 304.9 billion tons and precisely surveyed reserves are 98.8 billion tons (The Chinese Academy of Engineering 2011a, b; BP 2010). With improvements in technology and further development of coal exploration and mining, China's proven recoverable coal reserves are certain to continue increasing.

China is rich in coal resources, but they are unevenly distributed, being found more in the north and west and less in the south and east (Fig. 7.2):

1. In terms of the north–south distribution, coal resources are mainly located to the north of the Kunlun Mountains–Qinling–Dabie Mountains area: the total amount of coal resources in the provinces north of this line accounts for 93.1 % of the national coal resources, and the proven reserves account for over 90 % of the national reserves.

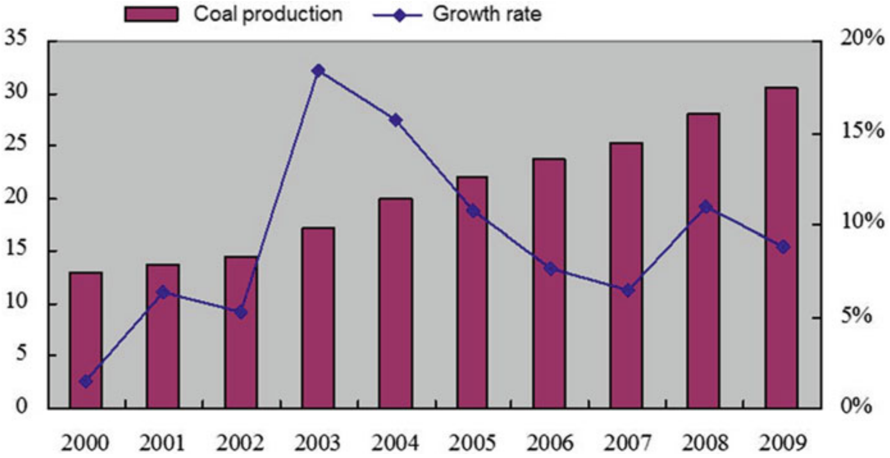

**Fig. 7.2** Coal production in China (2000–2009, unit: $10^4$ tons) (*Statistics source*: BP 2010)

2. In terms of the east–west distribution, coal resources are mainly located to the west of Daxinganling–Taihang Mountains–Xuefeng Mountains: in the 11 provinces west of this line, including Inner Mongolia Autonomous Region, Shanxi, Sichuan, and Guizhou provinces, the total amount of the coal resources accounts for 91.8 % of the national coal resources, and the proven reserves account for 89 % of the national reserves (Sidebar 7.1).

### Sidebar 7.1: Definitions of Coal Resources and Coal Reserves

1. Prospective reserves: according to geological forecasts, coal resources above a vertical depth of 2,000 m are defined as the total coal resources.
2. Recoverable reserves: accumulated proven coal resources, including both utilized and unused reserves. Unproven resources are defined as forecast resources.
3. Utilized reserves: utilized resources for production mines and those under construction can be divided into completely surveyed and incompletely surveyed resources. The completely surveyed reserves can form the basis for mine design and construction.
4. Unused resources: among recoverable reserves, these are reserves that have yet to be utilized. They can be divided as follows: completely surveyed, incompletely surveyed, standard-level surveyed, and unsurveyed reserves.
5. Proven recoverable reserves: among utilized completely surveyed reserves, after deducting the recovered resources, the remaining recoverable resources are defined as proven recoverable reserves.

In terms of coal quality, China possesses most varieties of coal, ranging from lignite to anthracite of different coalification levels, but their amounts and distribution are uneven. Because of the high ash and sulfur content, China has limited coking coal resources, and the supply of high-quality coking coal is even more restricted. The main disadvantage with highly metamorphosed coal (lean coal, anthracite) is the high percentage of sulfur. The average calorific value of Chinese coal is below that of internationally traded coal, but it is equal to that of the coal in many countries. The average calorific value of China's coal is 5,400 kcal/kg, while that of coal from the United States is 5,600 kcal/kg (IEA 2007; Mao 1999).

#### 7.2.1.2 Coal Production

The amount of coal production in China is huge, and the country ranks first in the world, accounting for 45.6 % of global output in 2009. In the last 30 years, coal's share among China's energy production has remained around 70 %. With the rapidly increased energy demand in recent years, there has been a swift increase in China's annual coal production—from 1.3 billion tons in 2000 to 3.05 billion tons in 2009; the average annual growth rate was 9.9 % (Fig. 7.2).

Coal production in China is mainly concentrated in Shanxi, Inner Mongolia, Shaanxi, Henan, Shandong, Guizhou, and Heilongjiang provinces. Newly increased production in recent years has mainly occurred in Shanxi, Shaanxi, Inner Mongolia, and Ningxia. According to the regional raw coal production statistics presented in the China Energy Statistics Yearbook 2010 (NSB and NEB 2011), the total annual coal production in those four provinces accounted for 34.6 % of national production in 2000; it increased to 52.4 % in 2009 and contributed to 60 % of the coal production increase during that period.

Although China's coal output has increased rapidly, it is now being produced beyond sustainable capability, and this has given rise to a number of problems (CAE 2011a; Pu 2010):

1. Low resource recovery rate: only 49 % of coal production (from state-owned key coal mines) can achieve recovery rates of over 50 %; 16 % of coal production (from state-owned local coal mines) achieves recovery rates of 30 %; the remaining 35 % of coal production (privately owned local coal mines) attains recovery rates of only 10 %.
2. Mining security problems: though in recent years, the death rate for every million tons of coal mined in China has been decreasing, the annual number of deaths in this industry is still the highest in the world. In 2008, the death rate for every million tons of coal mined was 1.184, which is 30 times higher than the number in the United States. There were 3,215 deaths in coal mining accidents in China in 2008.

3. Land subsidence problems: 95 % of coal production in China takes the form of underground mining, and mining subsidence is the main cause of land destruction by the coal industry. According to statistics, in 2005, land subsidence caused by coal mining affected more than 700,000 $hm^2$, and the land collapse was over 800,000 $hm^2$, resulting in economic losses of over RMB 50 billion. Currently, land subsidence caused by coal mining is increasing at a rate of 30,000–50,000 $hm^2$ per year. The problem is more severe in eastern areas of China, where land resources are relatively scarce.
4. Water resources and ecological environment problems: coal mining causes severe water pollution and destruction of water resources. According to estimates, 2.2 billion $m^3$ of groundwater resources are destroyed each year by coal mining in China. Coal resources and water resources are inversely distributed in China, and coal mining is constrained by scarce water resources. For example, in Shanxi, Shaanxi, Inner Mongolia, and Ningxia provinces, proven coal resources account for 64.4 % of the national resources, whereas water resources amount to only 2.6 %. At 13 large-scale mining sites in these and nearby areas, the daily water demand is about 900,000 $m^3$, but the local water supply can meet only half of that. At the same time, the areas of China in the north of Qinling–Dabie Mountains suffer from droughts and lack of rainfall; vegetation cover rate is low, and the ecology is fragile. Almost 90 % of China's coal resources are located in these areas, and the local ecology significantly restricts the development of coal.

#### 7.2.1.3 Coal Transport

As noted above, China's coal resources are mainly distributed in western and northern areas of the country; however, coal demand is mostly in the economically developed coastal areas in the east and south. Long-distance, large-scale transport of coal is thus inevitable, and the transport pattern is one of western coal being transported east, and northern coal being transported south.

In 2010, the total amount of transported coal was two billion tons (NEA 2011). China's coal transport mainly relies on railway with assistance from road transport, sometimes combined with shipping. For example, coal is initially transported by rail to coastal or riverside ports and then shipped to markets in southern areas. Rail transport handles almost half of the total coal production (Yue 2008). Further, coal is the chief commodity transported by rail, accounting for over 40 % of the rail transport load. In recent years, transport capacity has become one of the major constraints in China's coal supply. Long-distance, large-scale transport and transit inevitably result in high coal prices in southeastern markets.

#### 7.2.1.4 Coal Imports

In China's southeastern coastal areas, coal imports have been increasing in recent years as a result of scarce coal resources and limits in the coal transport capacity.

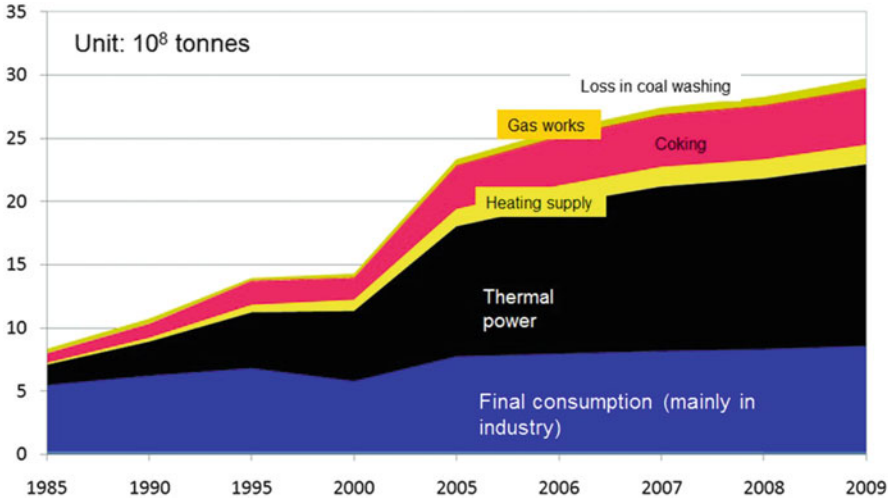

**Fig. 7.3** China's coal consumption (*Statistics source*: *China Energy Statistics Yearbook 2010*)

Thus, there has been a rapid rise in national coal imports. According to the Coal Balance Sheet in the China Statistics Yearbook 2010, China's annual coal imports grew from 2.18 million tons in 2000 to 126 million tons in 2009 (there was an increase of 40 million tons in 2008). In 2010, when the coal demand in international markets was relatively weak and prices were low, power plants in southeastern coastal areas purchased large amounts of coal on international markets; national coal imports thus dramatically increased, and the accumulated net annual coal import that year was 146 million tons (NEA 2011).

#### 7.2.1.5 Coal Utilization

In recent years, coal has maintained a level of 70 % of the national primary energy consumption. In 2009, China's annual coal consumption was 2,950 million tons—an increase of 210 million tons over the previous year. China's coal use includes the following (Figs. 7.3 and 7.4):

1. Concentrated power and heat generation: coal consumption by this sector has grown rapidly in recent years, and it currently accounts for over half of total consumption, with power generation being the major area. In 2009, 49 % of coal was combusted for power generation, and 5 % was for heat generation (heating supply).
2. Coking and gas works: this sector accounted for 15 % of total coal consumption in 2009. Until 2009, this sector was rapidly increasing, but since then it has been more stable. Coking is the dominant usage.

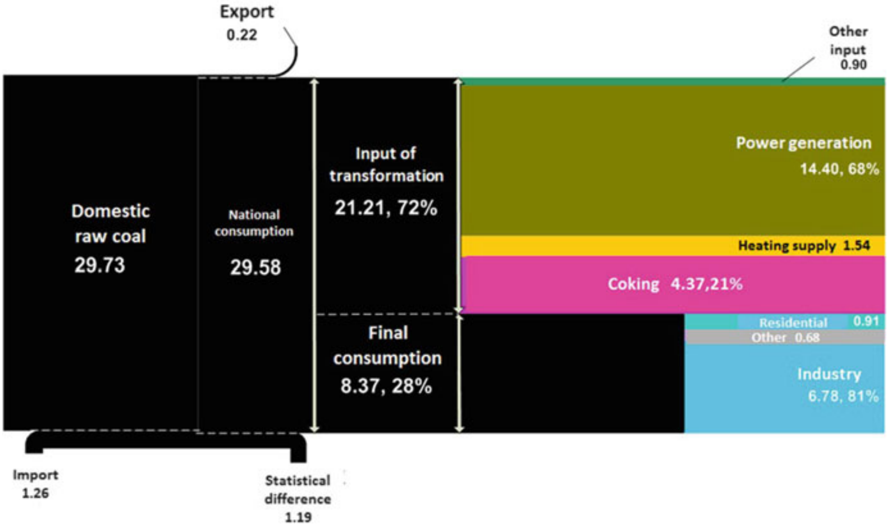

**Fig. 7.4** Coal flow in China, 2009 (unit, $10^8$ tons) (*Statistics source*: *China Energy Statistics Yearbook 2010*)

3. Final consumption: this sector includes fuel and raw materials for the chemical industry. In 2009, this sector accounted for 28 % of total coal consumption, mainly through combustion in industrial boilers or furnaces. In addition, 150 million tons of coal was consumed by the chemical industry (raw materials and production) in 2009, which compares with the 2000 figure of 88 million tons. The chemical products derived from coal include synthetic ammonia, methanol, dimethyl ether, and calcium carbide in addition to coal-derived liquid fuels.
4. Loss in coal washing: this amounted to 3 % of total coal consumption in 2009.

The large amounts of direct coal combustion result in severe environmental pollution in China. In 2007, China's $SO_2$ emissions reached 24.68 million tons, and $NO_x$ emissions were in excess of 20 million tons; coal combustion produced 80 and 70 %, respectively, of these emissions.

Coal combustion produces about 80 % of China's $CO_2$ emissions. With stricter environmental protection policies and the development of clean coal technology, conventional coal pollution may be reduced in future, but $CO_2$ emissions remain a problem.

The only way to achieve large-scale reductions in $CO_2$ emissions produced by coal is to implement carbon capture and storage (CCS) technologies. These capture the $CO_2$ emissions produced by coal and transport and store them in designated sequestration sites such that the $CO_2$ undergoes long-term isolation from atmospheric systems. However, owing to the considerable technical difficulties and the effect on energy efficiency and costs, there has been little chance thus far for this technology to be implemented on a large scale. However, China urgently needs to promote a complete CCS deployment project to examine its feasibility. Compared with the post-capture of low-concentrated $CO_2$ in the flue gas of coal-fired power plants, the pre-capture of high-concentrated $CO_2$ in the coal chemical industry offers advantages in terms of economic performance; it will thus be the preferred approach toward complete CCS deployment in China.

### *7.2.2 Constraints and Potential for Coal-Derived Vehicle Fuels*

Despite rich coal resources, China's coal mining industry faces problems with respect to mining security, destruction of water resources and the environment, and transport capacity. For example, the Chinese Academy of Engineering (CAE 2011a) comprehensively analyzed China's resource volume, mechanical mining, mining security, water resources, ecological preservation, and transport capacity, and it concluded that China's sustainable coal production cannot exceed 3.8 billion tons. If the above constraints are factored in, the actual level of sustainable coal production would be smaller (CAE 2011b): if only mining security and mechanical mining are considered as constraints, sustainable coal production would be 3.5 billion tons; if mining security, water resources, and ecological preservation are considered, sustainable coal production would be 2.9 billion tons; if transport constraints in Shanxi, Shaanxi, Inner Mongolia, and Xinjiang are also considered, sustainable coal production would be less than 2.5 billion tons.

In a situation of limited sustainable coal production, the rational allocation of coal resources remains a problem. At present, power generation, the steel industry, construction materials, and the chemical industry account for over 85 % of national coal consumption. According to forecasts by these major coal-consuming sectors, future coal demand will be 3.7–4.0 billion tons in 2030 and 3.5–3.8 billion tons in 2050. The chemical industry will require 0.35–0.4 billion tons of coal in 2030 and 0.4–0.45 billion tons in 2050 (CAE 2011a). Except for coal used to produce synthetic ammonia, calcium carbide, coal-to-olefin, and residential liquid fuels (e.g., dimethyl ether), coal used to produce vehicle liquid fuel can amount to no more than approximately 0.1–0.2 billion tons before 2050. If stricter sustainable coal production capacity constraints and $CO_2$ emission limits are considered, the actual coal resources for liquid fuel production would be less.

Local production of liquid fuels in coal-rich areas can help solve the coal transport capacity problem. Meanwhile, since coal-derived liquid fuel production consumes large volumes of water, depletion of local water resources will be a significant limiting factor. Referring to the interview with industrial experts, the average water consumed in producing 1 ton of coal-derived liquid fuel is about 10 tons.

Coal imports can partly solve the problems of domestic coal production capacity, but total coal consumption has to take $CO_2$ emission limits into consideration. Scenario analysis (CAE 2011b) has showed that to maintain $CO_2$ emissions below nine billion tons, China's coal consumption would have to be 3.2–3.4 billion tons by 2020 and thereafter decrease. It should be possible for China's increased energy demand to be met by nuclear power, natural gas, and renewable energy sources (CAE 2011b). CCS technology is not considered in the above scenario since its development is at an early stage, and it will probably not be commercially applicable in the near- to mid-term.

## 7.3 Technological Development of Coal-Derived Liquid Fuels

Coal-derived liquid fuel conversion technologies are advanced, clean technologies that convert solid coal into vehicle liquid fuels. Through various technical routes, coal can be converted into vehicle fuels, such as gasoline, diesel oil, methanol, and dimethyl ether. Fuels derived in this way can partly replace conventional petroleum-based gasoline and diesel that are currently in wide use.

This section will briefly introduce the development status of the above technologies. It will focus on an analysis of energy consumption, environmental emissions, and economic performances. It will also consider the influence of a carbon tax in direct coal liquefaction, indirect coal liquefaction, coal-derived methanol, coal-derived dimethyl ether and present a WTT analysis. In addition, a six-dimension comprehensive evaluation method is developed to evaluate the advantages and disadvantages of coal-derived liquid fuel development.

### *7.3.1 Current Status of Technology*

#### 7.3.1.1 Direct Coal Liquefaction

China started studying direct coal liquefied technology in the 1970s. Bituminous coal and lignite are appropriate types for direct liquefaction, and the products are mainly gasoline and diesel. Though technologies developed over the last 30 years are different in many ways from older technologies, the basic principles and industrial methods are the same or similar. Following research and development efforts in recent years and the advent of new scientific approaches, technical development is now much more feasible (Du 2006).

From 1997 to 2000, the China Coal Research Institute cooperated with government departments and companies in Germany, Japan, and the United States toward the completion of large-scale pilot plants for Shenhua Coal, Yunnan Xianfeng Coal, and Heilongjiang Yilan Coal. The institute also conducted a pre-feasibility study of a direct liquefaction demonstration plant using three different types of coal. In August 2001, China's first coal liquefaction demonstration project—the Shenhua direct coal liquefaction project—was finally licensed with a total designed production capacity of 500 million tons of oil. In 2009, the project achieved production of one million tons/year. By the first quarter of 2011, the plant was operating at higher than 80 % of the designed capacity, generating over 200,000 tons of fuel products.

#### 7.3.1.2 Indirect Coal Liquefaction

Bituminous coal, lignite, and anthracite are appropriate types for indirect liquefaction, with the products being mainly fuels such as gasoline, diesel, naphtha, and jet fuel. In 1937, Japan introduced the Fischer–Tropsch (F-T) synthesis technology from Germany, whose core technology is a cobalt catalyst, to the sixth factory of China Jinzhou Oil. In 1943, an indirect liquefaction plant with a production capacity of about one million tons of crude oil per year was built by China Jinzhou Oil. After the founding of the New China, that plant made handsome profits. Following the discovery of the Daqing Oilfield, the Jinzhou synthetic oil plant ceased operations in 1967.

In the early 1980s, in the aftermath of the world oil crises and also taking the country's rich coal resources into account, China restarted research and development efforts into indirect coal liquefaction technology. The Institute of Coal Chemistry in the Chinese Academy of Sciences made some achievements in improving technology and catalyst development, and it conducted a number of industrial tests. In recent years, other domestic research institutions have carried out considerable research work in F-T synthesis. The Dalian Institute of Chemical Physics has examined F-T synthesis using a supported iron catalyst. Nanjing University and Nanjing Institute of Chemical Industry have developed two processes for the conversion of synthetic gas to gasoline using oxygenated hydrocarbons. Tsinghua University, the former Beijing Institute of Chemical Technology (currently named as Beijing University of Chemical Technology), and other institutions conducted a considerable amount of research into F-T synthesis on a small laboratory scale.

Many large enterprises and research institutes jointly funded a new company named Synfuels China, which was established in 2006 and aiming to commercialize the technology of indirect coal liquefaction. Shanxi Luan Mining Group built an indirect coal liquefaction polygeneration demonstration plant in 2008, whose annual production capacity is 160,000 tons of liquid fuels, in Changzhi, Shanxi, using Synfuels China's technology. Synfuels China has also cooperated with the Mongolia Yitai Group and Shenhua Group in the construction of two indirect coal liquefaction polygeneration demonstration plants whose annual production capacity is 160,000 and 180,000 tons in Erdos, Inner Mongolia. By 2009, the Luan Changzhi and Yitai Erdos projects had carried out successful test runs and were producing qualified oil.

#### 7.3.1.3 Coal-Derived Methanol

China's methanol industry has developed very rapidly in recent years: the total annual production capacity of methanol increased from under 1 million tons in

1990 to 16 million tons in 2007. According to the interview with industrial experts in 2010, the annual production capacity of methanol (using coal as the main raw material) in 2009 amounted to 25–26 million tons.

However, compared with advanced production equipment employed around the world, the unit capacity of methanol production plants in China is generally small, the technology is backward, and the energy consumption and production costs are high. Currently, China has about 200 methanol production plants, and most of them produce under 0.05 million tons; foreign methanol production plants are mainly large scale and use gas as the main raw material; 80 % of them produce 0.3 million tons per year. In addition, the cost of foreign methanol production plants is lower than in domestic plants.

In the area of automotive energy, China has conducted methanol car demonstrations in several provinces and cities. Among these, Shanxi has carried out methanol-gasoline closed pilot schemes all over the province; the proportion of gasoline in the mix was tested at 15 % (M15 gasoline) to 85 % (M85) and then at 100 % (M100). The heat equivalent of the different mixtures of methanol-gasoline was lower than with gasoline. On July 2, 2009, the Standardization Administration of China announced that the methanol-gasoline standard for vehicle use (M85) (GB/T 23799-2009) had been officially approved and that it would be implemented on December 1, 2009. However by April 2011, the standard for M15 was still under discussion.

#### 7.3.1.4 Coal-Derived Dimethyl Ether

In 2008, China's dimethyl ether (DME) production capacity had reached about 4.1 million tons/year, but the yield was only 2.05 million tons. This rate is quite low, though this production project is still in the initial phase. During the period of the Eleventh Five-Year Plan (2006–2010), proposed and under-construction DME projects had a total estimated production of about 5–8 million tons. Referring to the interview with industrial experts in 2010, it was estimated that China's DME productivity amounted to over ten million tons in 2009.

Currently, Shanghai Jiao Tong University, Xi'an Jiaotong University, and Jilin University are investigating DME vehicle fuels. The tests of DME vehicle development have been carried out in Shanghai, Shanxi, and Xi'an. From March 2006 to July 2007, the Shanghai DME car project had completed DME fuel car production with test runs using ten cars.

### *7.3.2 Comparison of Technical Performance*

This section will compare the technical performance of different coal-derived fuels from three aspects: technological indicators in the production of coal liquefaction (e.g., resource consumption, energy efficiency), economic indicators (e.g., investment, product costs), and direct environmental emissions (mainly $CO_2$, $SO_2$, and $NO_x$).

**Table 7.1** Technological, economic, and environmental indicators for various production technologies for coal-derived fuels

| | | Direct coal liquefaction | Indirect coal liquefaction | Coal-derived methanol | Coal-derived dimethyl ether |
|---|---|---|---|---|---|
| Technological indicators | Annual production (10,000 tons/year) | 250 | 250 | 60 | 20 |
| | Production technology | HTI | High-temperature /low-temperature synthesis | – | – |
| | Coal consumption (tce/GJ) | 0.065 | 0.076 | 0.064 | 0.067 |
| | Electricity consumption (kWh/GJ) | 12.80 | 18.53 | 19.2 | 24.11 |
| | Water consumption (tons/GJ) | 0.145 | 0.255 | 0.31 | 0.37 |
| | Energy efficiency (%) | 50.31 | 41.41 | 50.22 | 47.455 |
| Economic indicators | Investment (RMB/GJ) | 169.76 | 199.74 | 144.12 | 196.79 |
| | Product cost (RMB/GJ) | 41.41 | 53.45 | 46.54 | 62.23 |
| | IRR (%) | 10.16 | 8.615 | 14.91 | 10.63 |
| Direct environmental emissions | $CO_2$ (kg-C/GJ) | 20.09 | 35.17 | 26.55 | 29.815 |
| | $SO_2$ (kg/GJ) | 0.01 | 0.004 | 0.003 | 0.004 |
| | $NO_x$ (kg/GJ) | 0.09 | 0.160 | 0.17 | 0.17 |

*Sources*: Liu et al. (2009), Yu et al. (2006), Li (2003), Zhang et al. (2006), and Kuang (2009)

*Notes*:

1. Values in the table are average results derived from a comprehensive comparison of data in literature
2. IRR, internal rate of return
3. The heat value of direct and indirect coal-to-liquid fuels is 41.868 GJ/tons, methanol is 22.7 GJ/tons, and DME is 29.7 GJ/tons

Many related studies have been conducted in this field; data from the literature and average data chosen as performance parameters for coal-derived fuel production processes are presented in Table 7.1. A comparison of the resource consumption, energy efficiency, investment, production costs, and environmental emissions in direct coal liquefaction, indirect coal liquefaction, coal-derived methanol, and coal-derived DME production process are shown in Figs. 7.5, 7.6 and 7.7. In those figures, the technological, economic, and environmental indicators for direct coal liquefaction are used as a comparative basis (shown as 1); the indicators for other

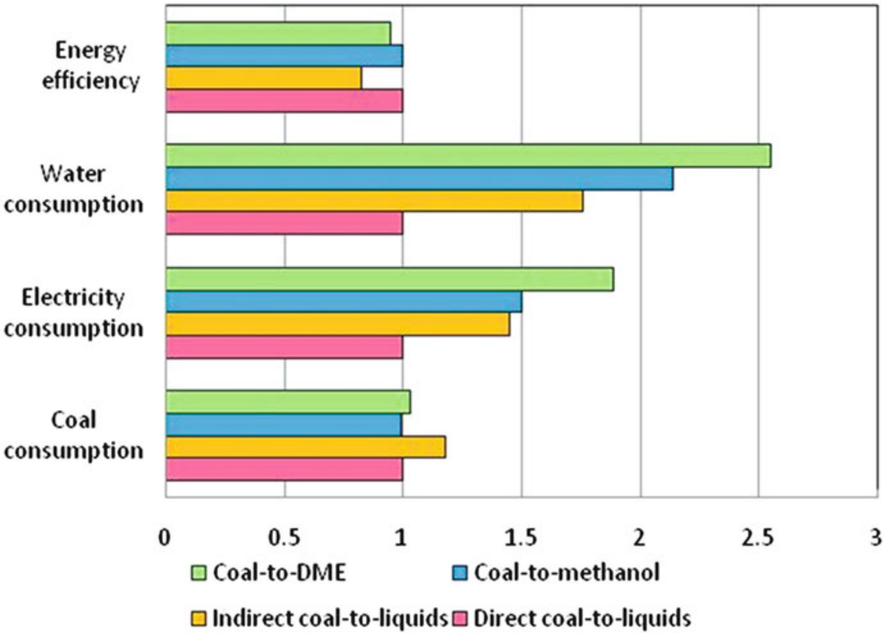

**Fig. 7.5** Comparison of technological indicators in the production of coal-derived fuels

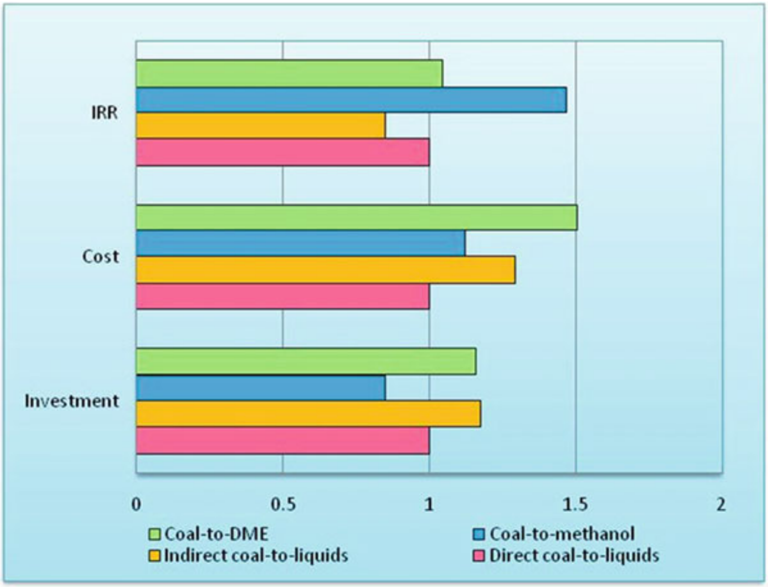

**Fig. 7.6** Comparison of economic indicators of coal-derived liquid fuel production

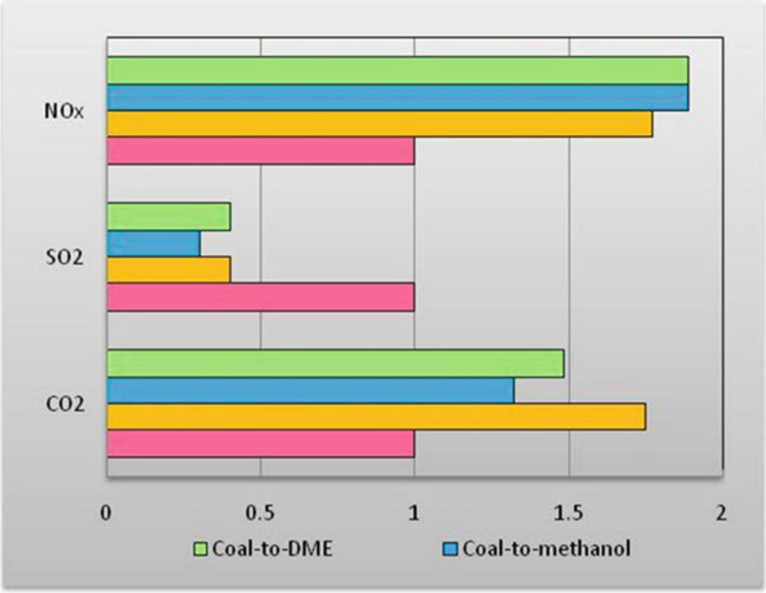

**Fig. 7.7** Comparison of environmental indicators in coal-derived liquid fuel production

production technologies are expressed as relative values. For example, in Fig. 7.5, indirect coal liquefaction of coal is 1.18-fold that of the direct coal liquefaction.

It is evident in Fig. 7.5 that coal consumption in indirect coal liquefaction is higher and leads to low efficiency in the corresponding production process. Overall, energy efficiency in the production process of coal-derived fuels is mainly in the range of 40–60 %. Electricity and water consumption are closely related to such factors as the specific process, type of equipment, and scale of production; however, it can be broadly stated from an examination of Fig. 7.5 that power and water consumption are higher with coal-derived DME. In the production of coal-derived fuels, the consumption of large quantities of water is a significant problem. Water consumption for coal-derived fuel is about 0.145–0.37 tons/GJ, which amounts to about 6.07–15.49 tons to produce 1 ton of oil.

Figure 7.6 shows the investment, product cost, and internal rate of return (IRR) of coal-derived fuel production. The investment and cost with indirect coal liquefaction and coal-derived DME are high, but the IRR is low; the investment and cost of coal-derived methanol are low, but the IRR is high. Therefore, in terms of economic performance, coal-derived methanol is superior to other coal-derived fuels.

Figure 7.7 shows the direct emissions of $CO_2$ and the air pollutants $SO_2$ and $NO_x$ in the process of coal-derived fuel production. $CO_2$ and $NO_x$ emissions in direct coal liquefaction are lower than with indirect coal liquefaction, coal-derived methanol, and coal-derived DME when producing 1 GJ oil; however, the $SO_2$ emissions are more than double those with the other three routes.

**Table 7.2** Industrial analysis of lignite from Xilinhot Shengli Coal Mine

| Industrial analysis | | | | | |
|---|---|---|---|---|---|
| $M_{\mathrm{daf}}$/% | $A_{\mathrm{d}}$/% | $V_{\mathrm{daf}}$/% | Calorific value (MJ/kg) ($Q_{\mathrm{gr,daf}}$) | $S_{\mathrm{d}}$/% | $C_{\mathrm{ar}}$/% |
| 19.56 | 17.03 | 43.47 | 26.3 | 1.52 | 39.71 |

## *7.3.3 WTT Analysis*

Since China's coal resources are mainly distributed in western and northern regions and the oil consumption market is largely in the southeast coastal region, long-distance transport is generally needed to transport coal from coal mines to the oil product market. Different combinations of transport modes result in different levels of energy consumption and greenhouse gas emissions in the WTT process. In conducting the WTT analysis in this section, the main focus is on the different energy consumption and greenhouse gas emissions among the alternative fuels used in the WTT process with different means of transport. To simplify the analysis, we consider only direct energy consumption and environmental emissions in the WTT process. This means that there will be no tracing back to the energy consumption and carbon emissions in the infrastructure, production, transport equipment, and other materials.

### 7.3.3.1 Basic Parameters and Routes Setting

Bituminous coal and lignite are both appropriate for the production of coal-derived fuel. Among China's coal resources, lignite accounts for about 70 %, and it is mainly distributed in Inner Mongolia, Xinjiang, and Yunnan. In the analysis presented in this chapter, lignite from the Shengli Coal Bed in Xilinhot, Inner Mongolia, is used as the source of coal. Industrial analysis of this type of coal is presented in Table 7.2.

The coal energy consumption factor in the mining process is about 0.016 tce/tons[1] and the emission factor is 131.9 g/kWh (SBQTC 2007; Ma 2002).

In this analysis, the oil consumption is centered in Shanghai. For the various coal-derived fuels, three production-transportation pathways are designed, as indicated in Fig. 7.8.

With current technological levels, it is difficult to transport methanol by pipeline, so only Pathway 2 and Pathway 3 are investigated with respect to methanol. The unit transport energy consumption and $CO_2$ emissions appear in Table 7.3.

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[1] The energy consumption limit of raw coal production in Shandong Province in 2008 was 5.2–15.58 kg tce/tons; the upper limit is used and rounded off for the purpose of this analysis as 16 kg tce/tons.

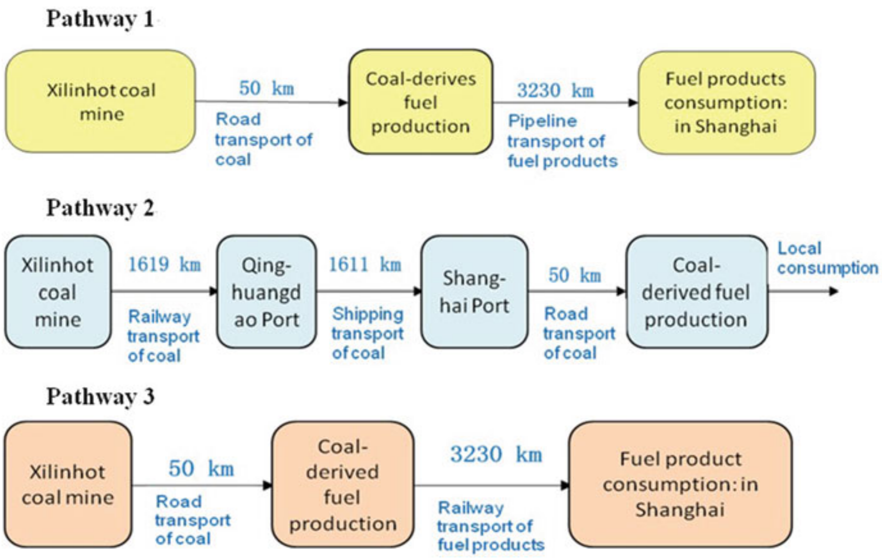

**Fig. 7.8** Production-transport pathway design for WTT analysis of coal-derived liquid fuels

**Table 7.3** Unit energy consumption and $CO_2$ emission by transport in China

| Transportation mode | Rail transport | | Road transport | Water transport | Pipeline transport |
|---|---|---|---|---|---|
| Energy consumption (GJ/tons · km) | 0.000260 | | 0.002147 | 0.000246 | 0.000405 |
| $CO_2$ emission (kg/tons · km) | Electric locomotives<br>0.0695 | Diesel locomotives<br>0.0192 | 0.159 | 0.0183 | 0.108 |

*Sources*: China Economic Herald (2008) and Wu et al. (2008)

*Notes*:

1. In this table, diesel locomotives in Rail transport, Road transport, and Water transport are all powered by diesel; electric locomotives in Rail transport and Pipeline transport are all powered by electricity
2. The data in the table were converted by the author from data in the literature. Among them, the $CO_2$ emission factor for diesel combustion in the internal combustion engine is 74.1 g/MJ and the $CO_2$ emission factor for thermal power is 267.753 g/MJ. $CO_2$ emissions in the transport process = energy consumption × $CO_2$ emission factor (kg/tons · km)

#### 7.3.3.2 Calculating Method

Assuming a loss of 0.6 % during transport, the energy consumption and $CO_2$ emissions of various coal-derived fuels can be calculated for coal mining, transportation, and oil production. The calculating method is as follows.

1. Amount of raw coal required to obtain 1 GJ liquid fuel:

$$M_{\mathrm{c}} = 1/(1 - \text{losses during transport}) \times \text{coal consumption in the production of 1 GJ liquid fuel}/\text{conversion factor in standard coal and raw coal} \tag{7.1}$$

2. Energy consumption and $CO_2$ emissions in the coal mining process:

$$E_1 = M_{\mathrm{c}} \times \text{power factor of coal mining} \tag{7.2}$$

$$P_1 = M_{\mathrm{c}} \times \text{calorific value of raw coal} \times \text{equivalent } CO_2 \text{ emission factor of coal mining} \tag{7.3}$$

3. Energy consumption and $CO_2$ emissions in the transportation process: when transporting raw coal,

$$E_{21} = M_{\mathrm{c}} \times \text{transport energy consumption factor} \tag{7.4}$$

$$P_{21} = M_{\mathrm{c}} \times \text{transport equivalent } CO_2 \text{ emission factor} \tag{7.5}$$

when transporting liquid fuels,

$$E_{22} = 1/(1 - \text{losses during transport})/\text{calorific value of liquid fuel}^2 \times \text{transport energy consumption factor} \tag{7.6}$$

$$P_{22} = 1/(1 - \text{losses during transport})/\text{calorific value of liquid fuel} \times \text{transport equivalent } CO_2 \text{ emission factor} \tag{7.7}$$

4. Energy consumption and $CO_2$ emissions in the production process:

$$E_3 = 1/(1 - \text{losses during transport})/\text{energy efficiency in the production process} \tag{7.8}$$

$$P_3 = 1/(1 - \text{losses during transport}) \times \text{equivalent } CO_2 \text{ emission factor in the production process} \tag{7.9}$$

Therefore, to obtain 1 GJ liquid fuel in the process from coal mining, transportation, and oil production to market energy consumption:

$$E = E_1 + E_2 + E_3 \tag{7.10}$$

$$CO_2 \text{ emissions } P = P_1 + P_2 + P_3 \tag{7.11}$$

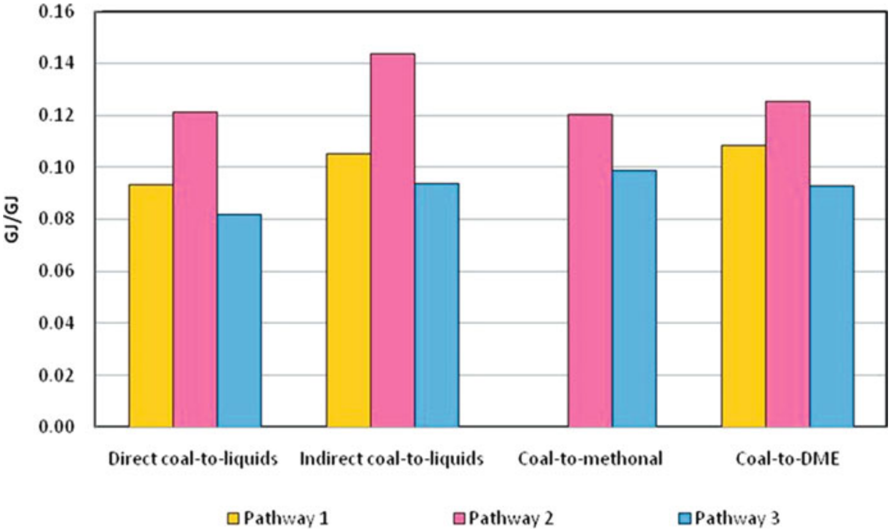

**Fig. 7.9** Energy consumption for coal-derived fuels WTT with the set pathways

### 7.3.3.3 Results and Analysis

From the results of the WTT analysis, in addition to the conversion process, coal mining and transport consume remarkable amounts of energy, whereas the $CO_2$ emissions in transportation account for only about 1–7 % of total emissions. The WTT energy consumption and $CO_2$ emissions with coal-derived liquid fuels appear in Figs. 7.9 and 7.10.

WTT energy consumption is very different with the same kind of coal-derived fuel production technology (Fig. 7.9): it is evident that energy consumption is relatively low in Pathway 3, though it is relatively high in Pathway 2. It is clear that building a coal-derived fuel factory near a coal mining area and undertaking long-distance transport of refined oil is an energy-saving option; by contrast, long-distance coal transport and building a coal-derived fuel factory near the refined oil market increases fuel consumption. In this analysis, energy consumption by long-distance pipeline transportation of refined oil is greater than that of rail transport—at least in terms of China's current level of pipeline development. With the development of pipeline transportation technology, long-distance pipeline transport has the potential for producing further reductions in power consumption.

For the same kind of coal-derived fuel production technology using a different mining–transport–production pathway, there is no significant difference in the equivalent $CO_2$ emissions (Fig. 7.10). This is because $CO_2$ emissions are mainly concentrated in coal mining and liquid fuel production links.

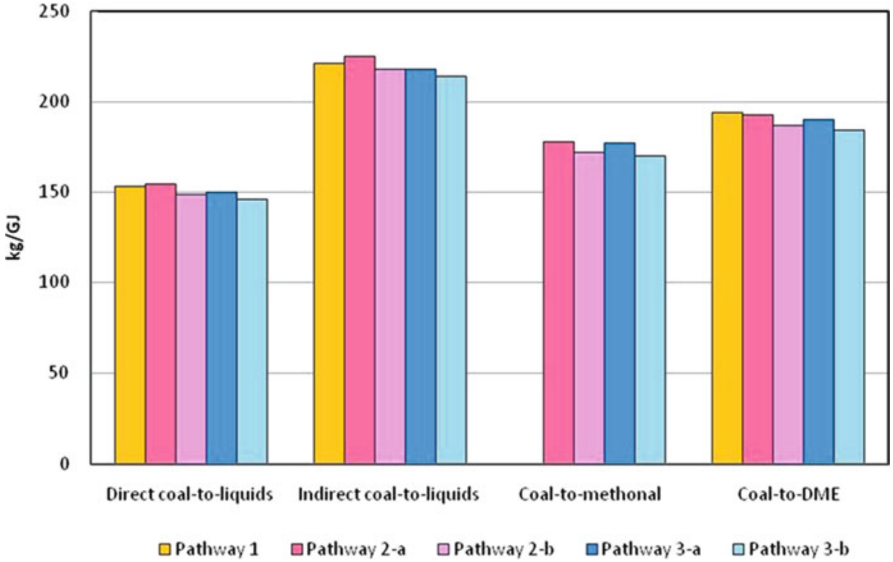

**Fig. 7.10** Equivalent $CO_2$ emissions of coal-derived fuels WTT with the set pathways. *Note*: A represents rail transport by electric train; b represents rail transport by diesel train

### 7.3.4 Influence of Carbon Tax on Cost of Coal-Derived Fuel Products

Throughout the entire WTT process of coal-derived alternative fuel conversion, considerable amounts of $CO_2$ are emitted to the environment—largely through emissions in the production links. Therefore, there is great potential for reducing $CO_2$ emissions with coal-derived fuel production links. Reducing $CO_2$ emissions not only depends on promoting particular technologies (such as CCS) but also demands certain policy support and guidance. Here, introducing a carbon tax is one possible future policy option for reducing greenhouse gas (GHG) emissions.

A carbon tax (GHG emission price) is a kind of pollution tax. It is levied according to the production, distribution, or use of fossil fuels based on the amount of carbon emissions after burning fossil fuels. With such a tax, government departments first determine a price for carbon emissions per ton and then calculate the taxes for electricity, natural gas, or oil according to that price. The tax increases the cost of polluting fuels, and it leads to reduced fuel consumption and energy-efficient improvements among public utilities, business organizations, and private individuals. In addition, a carbon tax can improve the cost competitiveness of alternative-energy sources such that they are able to compete with low-price polluting fuels.

The costs of coal-derived liquid fuels under different levels of carbon tax appear in Fig. 7.11. The cost of fuel increases with increasing carbon tax. The more $CO_2$

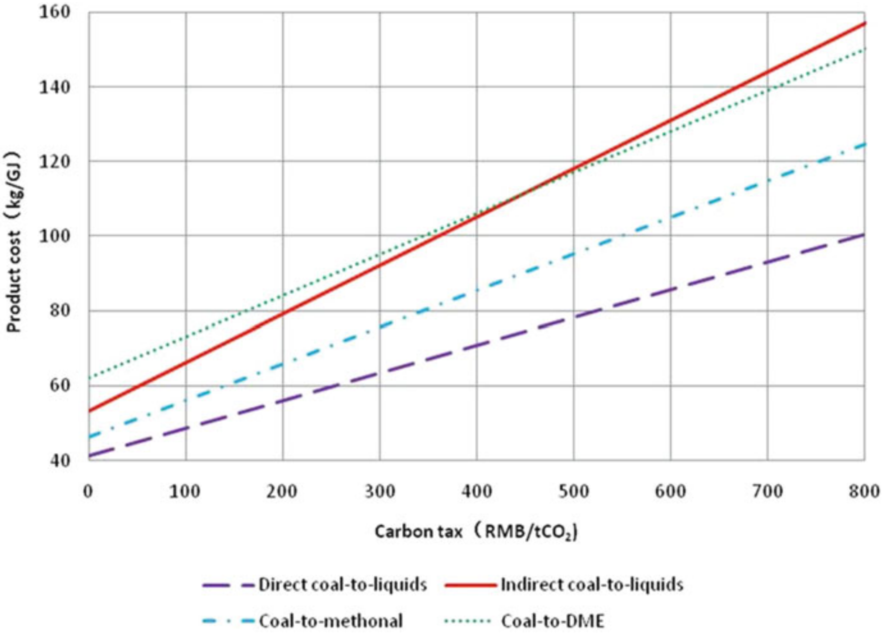

**Fig. 7.11** Cost of coal-derived fuels under a carbon tax

is emitted in the production of 1 GJ, the greater the curve's gradient in the figure; thus, there is a greater increase in the price for a particular increase in the carbon tax. If the carbon tax is lower than RMB 450/t$CO_2$, the production cost of indirect coal liquefaction is less than that of coal-derived DME; however, if the carbon tax is higher than RMB 450/t$CO_2$, the production cost of indirect coal liquefaction products is greater than that of coal-derived DME. At this point, coal DME acquires a certain competitive advantage since its $CO_2$ emissions are lower than with indirect coal liquefaction technologies.

### *7.3.5 Six-Dimension Comprehensive Evaluation*

The above analysis is a preliminary one that compares energy consumption, emissions, economy, and other technical factors for China's coal-derived liquid fuel. However, the development of coal-derived liquid fuels is a complex system, being influenced by energy, economic, environmental, social, and many other factors. Therefore, the following analysis represents an expansion of the original 3E (energy–economy–environment) framework by taking into account a comprehensive consideration of six dimensions—resource, environmental, economic, social, technical, and management factors; it makes a comprehensive evaluation of the benefits, costs, potential, and obstacles in the various types of coal-derived liquid fuel technologies (Ma et al. 2009).

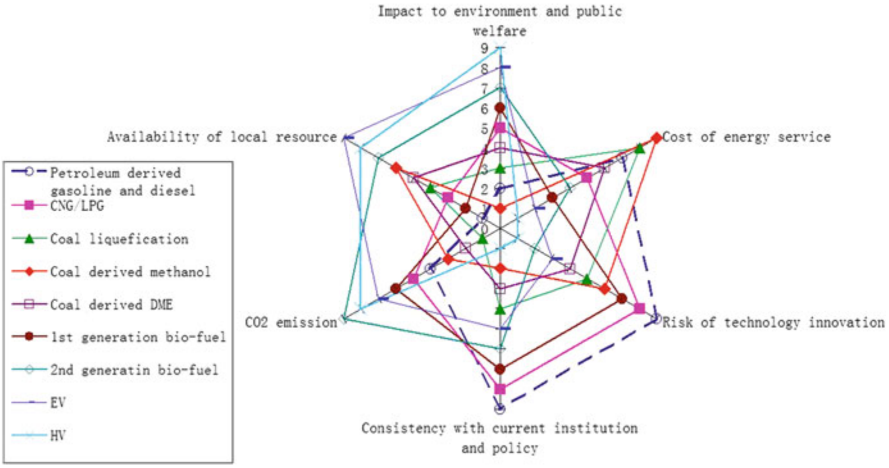

**Fig. 7.12** Results of six-dimension evaluation of coal-derived fuel compared with other forms of automotive energy

#### 7.3.5.1 Six-Dimension Evaluation Method

In making a unified evaluation and comparison of the six dimensions reflecting characteristic differences in various coal-derived liquid fuels, one core index was selected as the evaluation criterion for each dimension; these are presented in Fig. 7.12. In this analysis, other vehicle alternative fuels are also considered as references in the evaluation.

1. *Energy Security Dimension—Availability of Domestic Resources*

   The ability of alternative fuels to improve energy security is mainly related to the availability of domestic resources, such as resource reserves and energy supply capacity. In this regard, renewable energy is, generally speaking, superior to fossil energy, and coal is better than oil and gas. Biomass is considered to be inferior to wind and solar power because biomass energy consumes land and water, both of which are scarce in China, and the prospect for energy crops is uncertain.
2. *$CO_2$Emissions*

   These mainly relate to the international analysis results of $CO_2$ emissions in the WTW life cycle of different kinds of alternative vehicle fuels (Pehnt 2006; WBCSD 2007).
3. *Economic Dimension—Energy Service Costs*

   Energy service costs mainly depend on energy production costs, such as power costs and liquid fuel production costs. These costs are also related to the compatibility of the existing infrastructure, such as with regard to power grids, gas distribution systems, and automotive diesel system. In terms of the economic efficiency dimension, the existing infrastructure needs to be fully utilized because the cost of building new infrastructure is high and perhaps cannot be supported.

4. *Social Dimension: Effects on the Environment and Public Welfare*

   This dimension is affected by many factors, and it can also be understood as public acceptance. Emissions from conventional sources are not the sole important factor here; for example, methanol toxicity, the impact of wind farms on the local ecology, and the safety of nuclear power need to be considered (technically, however, these may not present substantial problems).
5. *Technical Dimension: Technological Innovation Risks*

   Technological development generally proceeds through four stages—research and development, demonstration, promotion, and commercialization. Different obstacles occur at these different stages, such as technical barriers, engineering barriers, and cost barriers, and these produce some risk. In general, the more advanced the technology appears to be, the greater is the potential risk.
6. *Political Dimension: Accordance with Existing General Principles*

   The existing general principles can be understood as the current basic state policy, such as with respect to energy conservation and development of renewable energy. Coal-derived fuels often lack the necessary policy and regulatory support. If inconsistent with existing general principles, commercial application of alternative fuels will usually take longer and may even be postponed indefinitely.

#### 7.3.5.2 Evaluation Results and Analysis

To better display the characteristics of the six dimensions with respect to various forms of alternative energy, this analysis adopts a uniform method of combining scores with radar diagrams in presenting the evaluation results. The rating criteria are divided into 10 levels (0–9 points), with a higher point representing better performance of that dimension; a larger coverage area of the curves represents better combined performance of the six dimensions.

The various technical routes, their corresponding dimensions, and their relative merits are presented in Fig. 7.13 (coal liquefaction in the figure includes direct and indirect coal liquefaction). It is evident that petroleum-based liquid fuel is the best in terms of technical and economic feasibility. Alternative technologies, such as electric cars, second-generation biofuels, and hydrogen/fuel cells, are the most favorable regarding long-term energy security and climate change, and they are also in accordance with political requirements and the public need. However, in economy, they are far behind more expedient alternative technical routes, such as coal-derived fuels, first-generation biofuels, and natural gas vehicles.

It is evident from this analysis that the advantages of general coal-derived liquid fuels are in their benefits through energy security and economy. Their common disadvantages are high $CO_2$ emissions, divergence from existing political objectives, and poor social acceptance. Achieving large-scale development of coal-derived liquid fuels in the future demands considerable efforts to be made in CCS, energy saving, publicity, and education.

It is also possible to make observations about the individual merits of several coal-derived liquid fuels (coal liquefaction, coal-derived methanol, coal-derived

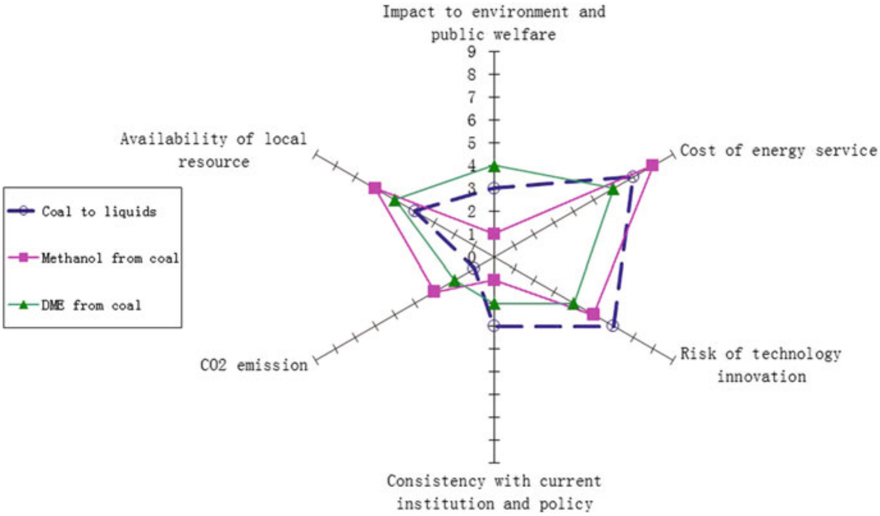

**Fig. 7.13** Results of six-dimension evaluation of coal-derived fuel

DME) from the results in Fig. 7.13. It is evident there that the main problems relating to coal-derived methanol are in the political and social dimensions; this fuel performs well in the other dimensions. Apart from its high carbon emissions, the main problem with coal liquefaction is that coal-derived DME has no obvious advantages except for better social acceptance. Hence, we can conclude that vehicles powered by coal-derived methanol should be promoted by focusing on their political and social acceptance, and coal liquefaction needs to effectively solve the problem of $CO_2$ emissions. There are no advantages in promoting coal-derived DME vehicles except for their social acceptability.

## 7.4 Development Strategy for Coal-Derived Liquid Fuel

This section aims to briefly review the development status of various coal-derived liquid fuels, focus on the obstacles and potential benefits facing their future development, and provide appropriate policy recommendations (Ma et al. 2008).

### *7.4.1 Analysis of Different Technology Pathways*

#### 7.4.1.1 Coal-Derived Methanol

Current situation: undergoing rapid expansion, surplus production capacity; local demonstration and promotion projects.

Major obstacles: mainly industrial policy issues. There is a lack of clear guidance policies and industry standards (M15 standard) at the national level, and there are some public acceptance issues. Some minor technical issues regarding engine corrosion, exhaust gas treatment, and other aspects remain to be solved.

Future potential: recent applications are mainly seen in gasoline blending and the development of the M85/M100 motorcade. Long-term potential development lies in methanol flexible-fuel automobiles and using the large amount of methanol storage to accommodate short-term disruptions in the oil supply or rise in oil prices.

#### 7.4.1.2 Coal-Derived DME

Current situation: undergoing rapid expansion, surplus production capacity; Shanghai is promoting demonstration of DME in public transport.

Major obstacles: mainly engineering problems. Research and development of vehicle technology are required in addition to construction of the supporting infrastructure.

Future potential: has the possibility of being an alternative fuel to diesel in the medium and long term, depending on the development and promotion of vehicle technology.

#### 7.4.1.3 Direct Coal Liquefaction

Current situation: in the commercial demonstration stage; the economy of such vehicles still needs to be proved in industrial practice.

Major obstacles: mainly engineering problems—how to achieve large-scale, stable, continuous industrial production; quality problems with synthetic oil. High energy and water consumption and large emissions of $CO_2$ in the production process will affect the long-term promotion of coal liquefaction.

Future potential: an alternative to diesel fuel; also, there is a promising market for liquefied oil in the short to medium term as an alternative to oil in non-transport use (fuel oil and petrochemical raw materials).

#### 7.4.1.4 Indirect Coal Liquefaction

Current situation: in the demonstration stage; independent indirect coal liquefaction technology has been developed. The economic efficiency still needs to be evaluated in large-scale industrial demonstrations.

Major obstacles: mainly engineering problems and the need to accumulate experience in industrial production and operation. It faces similar problems to direct coal liquefaction regarding resources and environmental aspects.

Future potential: as transport oil, it is compatible with existing vehicles and the existing infrastructure; there is also the possibility of cogenerating some chemical products.

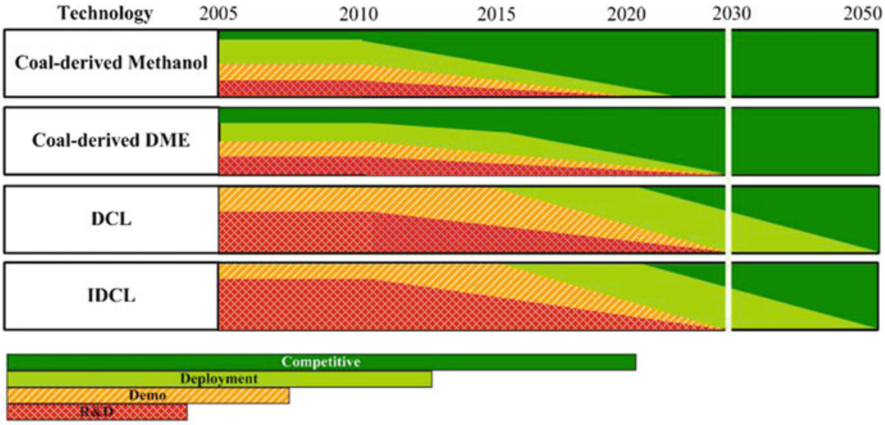

**Fig. 7.14** Policy recommendations for the development of coal-derived liquid fuels (policies to be adopted at different times)

### *7.4.2 Policy Recommendations for Comprehensive Development*

Development policies for different kinds of coal-derived alternative fuels for 2050 are made using the above analysis. As shown in Fig. 7.14, a recent key point has been the promotion of coal-derived methanol and ongoing commercial demonstrations of coal-oil fuels. After 2020, the development of coal-derived alternative fuels will depend on the energy security situation and overall national considerations regarding climate change. However, in light of the constraints facing sustainable coal production capacity and the current state of development of CCS, it is expected that the total size of the coal-derived liquid fuel market will not be very large.

Based on the above analysis, we make the following main policy recommendations for the development of coal-derived liquid fuel.

1. Coal-derived methanol: provide clearer industry guidance policies and industrial standards; expand the range of the project demonstrations; focus on the development of a full-fuel closed-running fleet and flexible-fuel vehicles. Industrialization should basically be achieved by 2015.
2. Coal-derived DME: focus on promotion by means of DME bus demonstrations; the industrialization of DME as a replacement for diesel should basically be achieved by 2020. As a substitute for diesel, coal-derived DME is an important way to deal with the possible problem of a future shortage of diesel.
3. Direct/indirect coal liquefaction: continue to promote business demonstrations and take further steps in improving product quality and reducing production costs, accumulate operating experience regarding industrialization, and make this a strategic technology reserve for energy security. After 2015, a modest promotion of this technology can be made depending on energy security needs.

## 7.5 Conclusions and Suggestions

### *7.5.1 Conclusions*

#### 7.5.1.1 Limited Potential Resource Supply of Coal-Derived Liquid Fuels

Although China has abundant coal resources, coal mining faces many problems, such as safety in production, limited water resources, and environmental protection. Current production capacity has already reached the sustainable level, which is only three billion tons per year. This means that increased coal production will become more and more difficult. It is possible to ease domestic coal production capacity constraints by importing coal and generating electricity in coastal regions. However, the total consumption of coal will still be restricted by overall $CO_2$ emission control, and it will be limited to about three billion tons a year owing to the unclear future regarding CCS technology. In addition, given that various other sectors and industries also have a huge demand for coal, it is estimated that coal resources that can be used to produce coal-derived liquid fuel will be 200 million tons or less per annum before 2050.

#### 7.5.1.2 Improving Technical Performance of Coal-Derived Liquid Fuels

Coal-derived liquid fuels have recently undergone rapid technological development in China. With some technologies, China is at the forefront of world development efforts. However, in general, the technical performance of coal-derived liquid fuels needs to undergo further improvement. An analysis of the literature shows that the energy efficiency of conversion of coal-derived liquid fuel is only 40–60 %, and 6.1–15.5 tons of water are consumed in the production of 1 tons of oil products. Except for coal-derived methanol, direct and indirect coal liquefaction projects and coal-derived DME projects have an IRR of under 12 %; this means that they have poor ability to resist such fluctuations as increases in the price of coal and falling oil prices.

The result of WTT analysis indicates that the production of liquid fuel near coal mines results in lower energy consumption and lower emissions. The development of coal-derived liquid fuels also faces the problem of scarce water resources. In addition, a carbon tax will probably lead to higher costs of coal-derived liquid fuel production—especially for indirect coal liquefaction with higher $CO_2$ emissions. Overall, the technical performance of coal-derived liquid fuels need to be further improved.

#### 7.5.1.3 Controlling the Total Production Capacity of Coal-Derived Liquid Fuels

The evaluation results of the integrated six-dimension analysis (resource, environmental, economic, technological, political, and social factors) indicate that coal-derived liquid fuel is stable in terms of technological and economic performance and is conducive to energy security. However, the development of coal-derived liquid fuels should not proceed too quickly owing to their poor public acceptance and high GHG emissions, which would make them a political target. To promote the large-scale development of coal-derived liquid fuels, more attention should be paid to CCS, energy saving, and appropriate consumer education.

A policy analysis of the development of coal-derived liquid fuels up to 2050 shows that it is necessary to promote coal-derived methanol and continue the construction of coal liquefaction commercial demonstration projects. The development of coal-derived liquid fuels after 2020 depends on China’s status in terms of energy security and considerations regarding climate change. Overall, an excessively large capacity of coal-derived liquid fuels should be avoided because of coal production limits and lack of clarity regarding the future of CCS technology.

### *7.5.2 Suggestions*

#### 7.5.2.1 Steady Development of Coal-Derived Liquid Fuels

At a certain scale, the development of coal-derived fuels can contribute to national energy security. However, considering their negative effects and poor public acceptance, it would be inappropriate to develop coal-derived liquid fuels in a rapid fashion and on too great a scale. When choosing local production projects, coal resources, water resources, and environmental capacity need to be carefully considered. At the same time, more attention should be paid to education and publicity to achieve a better public understanding of coal-derived liquid fuels.

#### 7.5.2.2 Promote Utilization of Methanol as Vehicle Fuel, Continue Commercial Demonstrations of Coal Liquefaction

Under the premise of normal, safe, long-term operations, coal-derived methanol for vehicle use offers advantages in terms of assured production capacity and lack of risk. Thus, coal-derived methanol can be considered an important development direction for coal-derived liquid fuel technology. Regarding public acceptance, technological improvements, and infrastructure construction, the focus in the development of coal-derived liquid fuels should be on their promotion in certain regions of the country rather than nationwide.

On the basis of existing technical and commercial demonstrations of coal liquefaction, demonstration projects should be further established; technical, economic, and environmental performance need to be further improved so that coal liquefaction can develop as a national energy security reserve. More research projects on vehicle technology and lower fuel costs should be the directions of development for coal-derived DME. As a substitute for diesel, coal-derived DME is an important way of dealing with the possible problem of future diesel shortages.

#### 7.5.2.3 Improve Research and Development of Energy-Saving, Emission-Reduction Technologies of Coal-Derived Liquid Fuels

More efforts are needed in the research and development of energy and water conservation as well as emission-reduction technologies for the production of coal-derived fuels. Under the constraints of national GHG emissions, CCS would appear to be a key technical solution for the large energy consumption and $CO_2$ emissions of coal-derived liquid fuel production. Meanwhile, $CO_2$ capture in coal-derived liquid fuel production has more technological and economic advantages than $CO_2$ capture in a coal-fired power plant. Therefore, application of coal-derived liquid fuel CCS technology should be promoted.

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