Chapter 5
Petroleum-Derived Liquid Fuels

Li Zheng, Fu Feng, Ma Linwei, Liu Pei, Zhou Zhai, Zhang Jianbing, and Jiang Xiaolong

Abstract In this chapter, after a brief introduction, we examine the development status and historical trends of oil development in China. A Sankey diagram of the oil flow in China from crude oil supply to the final sectors of oil product consumption is mapped to indicate the physical patterns of oil supply and consumption. Following this, we review the current status and historical trends of oil reserves, oil imports, oil refining, oil demand, oil prices, and related policies to present the multidimensional status of oil development in China. Then, we review existing opinions on future oil demand, especially that by road vehicles, future oil production, and energy security issues, and we summarize the future challenges facing oil development in China. Based on a scenario analysis of Chinese oil consumption up to 2030, we discuss a coping strategy for energy security and emission reduction, and we conclude with several policy suggestions for the future development of petroleum-derived fuels for road vehicles.

Keywords Petroleum • Liquid fuel • Oil • Scenario

5.1 Introduction

Globally, petroleum is both the dominant energy source for transportation and the most important primary energy source. According to global energy statistics issued by the International Energy Agency for 2008 (IEA; IEA 2010a), petroleum-derived

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fuels[1] accounted for 93.5 % of energy consumption in the transportation sector and that sector accounted for 61.4 % of the total petroleum consumption; further, petroleum accounted for 33.2 % of global primary energy consumption. However, the high dependency on oil (petroleum and petroleum-derived fuels) for transport and overall global energy consumption is creating serious problems involving energy security, greenhouse gas emissions, and pollution. Therefore, the major oil-consuming nations are highly concerned about conserving oil, oil security, making cleaner use of oil, and developing alternatives to oil.

At the beginning of the twenty-first century, China entered a stage of simultaneous industrialization, urbanization, and motorization, and the broad popularization of automobiles has become one of the distinctive characteristics of the current era. Propelled by various increasing demands, particularly the rising vehicle population, the total oil consumption has sharply increased. Owing to relatively low domestic petroleum reserves, China's oil imports are rapidly rising. By 2009, China's oil import dependency (OID) had surpassed 50 %. Meanwhile, volatility in the international price of oil in recent years has added to concerns over energy security. In some major cities in China, automobile exhausts have become the dominant source of NO_x and CO in the air (Lu et al. 2008). In addition, oil is second only to coal in terms of China's primary energy consumption, and oil accounts for roughly 18 % of China's primary energy[2]; thus, oil use has to be a focus of greenhouse gas (GHG) mitigation in China.

The above issues have raised concerns and produced differing views among experts and scholars over future perspectives regarding petroleum-derived fuel as the major source of automotive energy in China. Their views cover almost all possibilities: some believe we should completely disengage from our dependence on petroleum-derived fuels; others support the proper development of alternatives as a prudent supplement to petroleum-derived fuels; still others maintain that we should be solely dependent on petroleum-derived fuels. All these opinions are reasonable to a certain degree, but no single view has prevailed. It is therefore more important to discuss how measures might be adopted against existing problems before attempting to prove one or other of the above beliefs.

Thus, this chapter does not aim to make accurate projections regarding the future development of petroleum-derived fuels for automotive energy. It attempts to analyze the currently available information (predominantly for 2000–2009) by examining and balancing various views, discussing key issues on the future development of petroleum-derived fuels, and presenting possible scenarios that may result in addition to various internal mechanisms of such scenarios. Following this, the present chapter tries to make some preliminary strategic suggestions with respect to the future development of petroleum-derived fuels for automotive energy.

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[1] Named "oil products" in the IEA publication.

[2] The actual proportion depends on the calculation method: the figure is 18.8 % when calculated in terms of calorific value calculation, 17.9 % in terms of the coal equivalent.

It is also worth noting that the discussions in this chapter focus on the future prospects for automotive energy. However, owing to the fact that these issues involve the whole energy-supply chain—from oil production, oil imports, and oil refining to the final consumption of oil products, which are not only used for road vehicles—the subject matter of this chapter is the entire oil-supply chain, rather than just that relating to the road transportation sector.

The main contents of this chapter are as follows. Section 5.1 is an introduction to the study background and subject matter. Section 5.2 presents the development status and historical trends, which includes a literature review and data analysis of the development status and historical trends of oil reserves, domestic crude oil production, strategic petroleum reserves (SPR), oil refining, oil demand, oil prices, and oil-related environmental policy. In this way, Sect. 5.2 provides data to support subsequent discussions. Section 5.3 examines future perspectives and corresponding measures. It first summarizes previous studies on future perspectives of China's oil development before conducting a scenario analysis and strategy analysis on key issues, including oil consumption, vehicle gasoline and diesel consumption, binding targets of China's energy security, the oil gap, pollution, and GHG mitigation. Section 5.4 offers conclusions and suggestions. It summarizes the major opinions regarding the future development of petroleum-derived fuels for automotive energy in China.

5.2 Development Status and Historical Trends

5.2.1 Oil Flow in China

To offer an overall understanding of China's oil supply and consumption on a purely physical basis, we mapped the entire oil flow in 2009 in the form of a Sankey diagram. For this, we used data from the 2009 Oil Balance Sheet in the *China Energy Statistical Yearbook 2010* (DESNBS and DGANEA 2011) as well as energy statistics from Wang (2010). The diagram appears in Fig. 5.1.

In this diagram, the entire oil flow in China is presented by means of a series of arrows according to sector and oil type. The width of the arrows denotes the scale, while the color distinguishes the different types of oil. The overall oil chain is divided into five subprocesses.

1. Crude oil: this includes crude oil production, oil imports, oil exports, oil stocks, own use of oil (consumption by the energy industry, including the consumption in energy exploitation, transformation, and allocation, predominantly in the petroleum industry), oil transportation loss, and industrial consumption of crude oil.
2. Oil refinery: here crude oil is refined into various oil products, though there is a significant amount of refining loss.

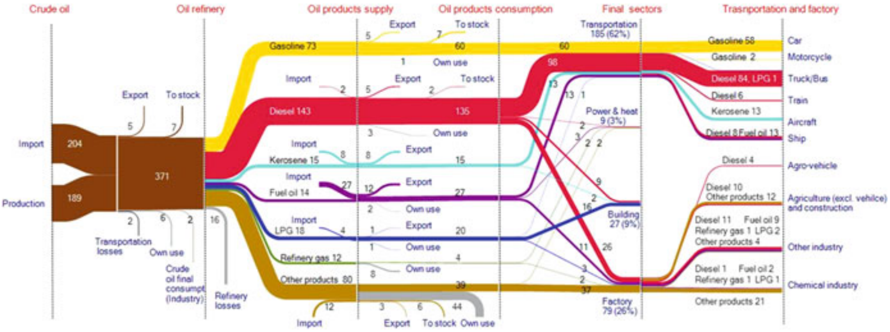

Fig. 5.1 Oil flow in China (2009; unit, Mt) (*Data source*: DESNBS and DGANEA 2011; Wang 2010)

3. Oil products supply: this includes the import, export, stock, and own use of various oil products.
4. Oil products consumption: this includes consumption by transportation, power and heat generation, buildings (including the service industry, residential consumption, and other consumption in the oil balance sheet), and other industries (manufacturing, agriculture, and construction).
5. Final sectors: this part further presents a detailed breakdown of consumption of oil products in transportation and by factories: the former includes cars and motorcycles, trucks and buses, trains, aircraft, and ships; the latter includes agricultural vehicles, agriculture, the construction industry, the chemical industry, and other industries (Sidebar 5.1).

Sidebar 5.1: Data Adjustments for the Oil Balance Sheet to Map the Oil Flow Diagram

Although the 2009 Oil Balance Sheet for China provides data on oil consumption by sector and oil type, certain adjustments are required owing to issues related to the statistical methods employed. The major adjustments are as follows:

1. Adjustments to transport oil consumption: oil consumption by transportation in the balance sheet applies only to transport-operating sectors; some oil is also consumed in other sectors by road vehicles. According to the method suggested by Wang (2010), 95 % of gasoline and 35 % of diesel consumed by light and heavy industry, the construction industry, and service industry is moved to “transportation” in the balance sheet, whereas all the gasoline and 95 % of diesel consumed in living is moved to “transportation.”

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2. Adjustments to industrial oil consumption: oil consumption by certain energy-related industries is included in "industrial consumption" in the balance sheet. This oil is in fact consumed by energy-supply industries; thus, it should not be considered the final consumption; it should be accounted as own use of oil by the energy-supply sector. Five departments should be excluded from industrial oil consumption: mining and washing of coal, extraction of petroleum and natural gas, processing of petroleum, coke, and nuclear fuel (which accounts for roughly 76 % of the total own use), production and distribution of electricity and heat, and production and distribution of gas.

From Fig. 5.1, the main characteristics of China's oil production and consumption of oil can be summarized as follows:

1. High import dependency on crude oil: in 2009, domestic crude oil production was 189 Mt, while imports amounted to 204 Mt.
2. Oil products are mainly supplied by domestic oil refineries: in 2009, domestically produced oil products amounted to 355 Mt, whereas imported oil products stood at 53 Mt.
3. Oil products are predominantly consumed by transportation, especially road transport: in 2009, China's total oil consumption (including losses and own use) was 385 Mt, and the final consumption of oil products amounted to 300 Mt. The transport sector consumed 185 Mt of oil products, which was 48 % of the total oil consumption and 62 % of the total final consumption of oil products. In particular, road transport (cars, motorcycles, trucks, and buses) accounted for 78 % of the total consumption of oil products in the transport sector.
4. Gasoline and diesel is mainly consumed by road transport, whereas diesel consumption by road transportation is greater than that of gasoline: almost all the gasoline is consumed by road transport. In contrast, diesel is used more diversely, and only 62 % is consumed by road transportation. In total, road transport consumes 84 Mt of diesel and 60 Mt of gasoline.
5. Light and heavy industry is the second-largest oil-consuming sector, and it mainly consumes "other products": in 2009, 79 Mt of oil products and 81 Mt of oil (plus crude oil) were consumed by factories, which accounted for 26 % of the final consumption of oil products and 21 % of the total oil consumption. Among factory-consumed oil products, 45 % were "other products," 60 % of which were used in the chemical industry. Diesel consumption by agriculture and the construction industry is relatively large in scale; in particular, the construction industry used almost one-third of the "other products" of factories. Among other industries, the materials industry accounted for the greatest consumption of oil products, mainly through consuming fuel oil and diesel.

6. There was large-scale own use, especially for processing petroleum: in 2009, own use of oil amounted to 66 Mt, which was 17 % of the total oil consumption. Of this own use, 83 % was consumed in processing petroleum, coking, and processing nuclear fuel.

5.2.2 Oil Reserves and Crude Oil Production in China

According to BP's statistics, proven oil reserves in the world have been continuously increasing over the past 10 years, amounting to 181.7 billion tons in 2009 (BP 2010). According to the magazine *Petroleum and Natural Gas*, the proven oil reserves are even higher—184.7 billion tons (IEA 2010b). According to IEA, the global recoverable reserves of conventional oil are 488 billion tons, and it suggests that only one-third of these reserves are actually proven (IEA 2008). Taking into account advances in oil exploration and extraction technology and the potential for using unconventional reserves, the global recoverable oil reserves may be as high as 887 billion tons (Sidebar 5.2).

Sidebar 5.2: Global Oil Reserves and Unconventional Resources

(a) *IEA Assessment of Global Oil Resources in WEO 2008* (*Summary*)
The world is far from running out of oil. Remaining proven reserves of oil and natural gas liquids worldwide at the end of 2007 amounted to about 1.2 trillion to 1.3 trillion barrels (including about 0.2 trillion barrels of Canadian oil sands). These reserves have almost doubled since 1980. Though most of the increase has come from data revisions made in the 1980s by the Organization of Petroleum Export Countries (OPEC) rather than from new discoveries, modest increases have continued since 1990, despite rising consumption. The volume discovered has fallen well below the volume produced over the last two decades; the volume of oil found on average each year since 2000 has exceeded the rate in the 1990s owing to increased exploration activity (with higher oil prices) and improvements in technology.

Ultimately recoverable conventional resources—a category that includes initially proven and probable reserves from discovered fields, growth in reserves, and economically recoverable oil that has yet to be found—amounts to 3.5 trillion barrels. Only a third of this total has thus far been produced. Undiscovered resources account for about one-third of the remaining recoverable oil, the largest volumes of which are thought to lie in the Middle East, Russia, and the Caspian region. Unconventional oil resources are also large. Worldwide, oil sands and extra-heavy oil

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resources amount to around six trillion barrels, of which between one trillion and two trillion barrels may ultimately be economically recoverable. These resources are largely concentrated in Canada (mainly in Alberta) and Venezuela (in the Orinoco Belt). There is additional potential from oil shales, but their production costs and the environmental impact of their commercialization are very uncertain.

(b) *Oil Shales, Heavy Oil, and Oil Sand* (*Chen et al.* 2009)

Oil shales are combustible mineral resources formed with minerals and organic matter. The composition of the minerals is very complicated: they largely include quartz, kaolinite, montmorillonite, and illite as well as external clay, sand, and salts. The organic matter is mainly composed of kerogen and bitumen, which are dispersed homogeneously in the mineral matrix.

Heavy oil is also referred to as thick oil, and it has high density ($\text{API} < 22$), high viscosity ($>10\ \text{mPa} \cdot \text{s}$), and a high bituminous content (nonhydrocarbon macromolecular compounds, which contain most of the sulfur and 90 % of the oil's heavy metals). Extra-heavy oil refers to heavy oil with an API lower than 10.

Bituminous oil sand, also referred to simply as oil sand, is a mixture of natural bituminous sand and soil. The natural bitumen extracted from oil sand has the characteristics of heavy oil, whereas the density and viscosity are greater than with heavy oil.

Although petroleum is still abundant globally, which suggests that the "oil peak" will not occur in the near future (according to the oil peak theory, when more than half of global resources have been exploited, crude oil production will plummet), the problem is the very imbalanced regional distribution of global oil resources. Almost 57 % of proven oil reserves are concentrated in the Middle East, whereas the intensively oil-consuming countries in North America, Europe, and the Asia-Pacific region are running short of oil reserves (BP 2010). Nearly all previous global oil crises and fluctuations in oil prices can be attributed to the high dependency on the global oil supply of oil-exporting countries in the Middle East. In addition, along with the depletion of conventional oil reserves, oil from enhanced oil recovery, deep-ocean resources, and unconventional resources is likely to account for an increasingly higher share in the global oil supply, which will drive up exploitation costs (IEA 2008) and raise oil prices in the future. Therefore, regional patterns of oil supply and demand and the cost of oil exploitation are more important than the total scale of oil reserves.

Regarding China, although proven oil reserves in 2009 were only two billion tons and the reserve/production ratio was as low as 10.7:1 (BP 2010), the country still has considerable potential for expanding its oil reserves. According to the results of

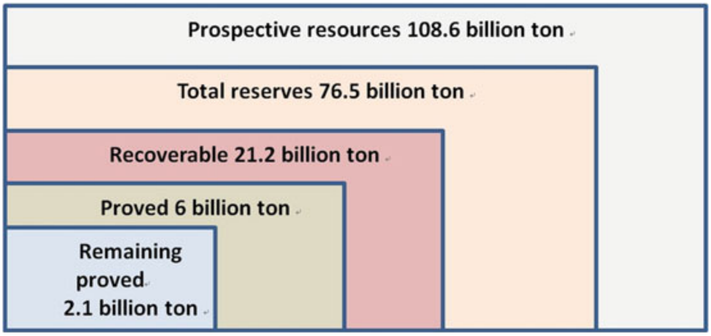

Fig. 5.2 Oil reserves of China—statistics from the Ministry of Land and Natural Resources

an assessment of national oil and gas reserves[3] conducted by the Ministry of Land and Natural Resources in 2007, China's recoverable conventional oil reserves stood at 21.2 billion tons (Fig. 5.2, Sidebar 5.3); only around 1/10 of those are proven. In addition, recoverable reserves of unconventional resources, such as oil shales and oil sands, are estimated to be 12 and 2.3 billion tons, respectively; these can be important supplements to conventional resources. Currently, the exploration and production of crude oil in China are making steady progress: crude oil production is expected to attain around 200 Mt by 2030. According to CAE (2011a), a crude oil production level of 180–200 Mt will be a secure and sustainable target by 2050.

Sidebar 5.3: Definitions of Oil Resources and Reserves in China

1. Prospective resources: the potential amount of oil or gas, that is, the probable maximum that can be exploited. In the assessment of resources conducted by the Ministry of Land and Natural Resources, prospective resources have a probability of 5 %.
2. Geological resources: the amount of oil or gas amount that can be proven using current techniques, including proven and unproven re-sources.
3. Recoverable resources: the amount of resources that can be exploited with future foreseeable technologies and economic conditions.
4. Proven recoverable reserves: under the specified economic, technological, and policy conditions, the developed and undeveloped oil or gas reserves.
5. Remaining proven recoverable reserves: for developed oil or gas reserves, the remaining proven recoverable reserves are equal to the recoverable reserves minus the amount of extracted oil or gas.

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[3] Refer to the report by the Xinhua News Agency on national petroleum and gas assessment: http://news.xinhuanet.com/newscenter/2008-08/18/content_9480784.htm

Table 5.1 China's oil production, imports, exports, and consumption, 1995–2009

Year	Production (Mt)	Imports (Mt)	Exports (Mt)	Stock (Mt)	Consumption (Mt)	OID (%)
1995	150.1	36.7	24.5	1.5	160.7	6.6
1996	157.3	45.4	27.0	−0.7	176.4	10.8
1997	160.7	66.0	28.2	4.5	194.1	17.2
1998	161.0	57.4	23.3	−2.2	197.4	18.4
1999	160.0	64.8	16.4	−1.2	209.6	23.7
2000	163.0	97.5	21.7	12.4	226.3	28.0
2001	164.0	91.2	20.5	2.6	232.0	29.3
2002	167.0	102.7	21.4	−0.9	249.3	33.0
2003	169.6	131.9	25.4	0.7	275.4	38.4
2004	175.9	172.9	22.4	5.2	321.2	45.2
2005	181.4	171.6	28.9	−1.3	325.4	44.3
2006	184.8	194.5	26.3	3.7	349.3	47.1
2007	186.3	211.4	26.6	4.6	366.5	49.2
2008	190.4	230.2	29.5	18.0	373.2	49.0
2009	189.5	256.4	39.2	22.1	384.6	50.7
Total increase	39.4	219.7	14.7	20.6	223.9	44.1

Data source: Table 5.6 from China Energy Statistics 2010 (DESNBS and DGANEA 2011)

Some major oil fields in China, such as Daqing Field, have been experiencing a continuous decline in oil output owing to depletion of oil reserves (Tang et al. 2010). However, through the exploration of new oil fields, advances in oil exploitation technology, and the potential in unconventional oil resources, the oil peak that was previously forecast by scholars as occurring in 2020 will probably take place considerably later (see Sect. 5.3.1.3). This conclusion, though, is built on the precondition that crude oil production will stabilize at 180–200 Mt. If that is not the case, China's oil peak will come earlier. In 2010, the crude oil production of China surpassed the 200-Mt mark (NEA 2011).

5.2.3 *Oil Imports and Strategic Petroleum Reserves of China*

Globally, the regional imbalance in oil production and consumption has led to large-scale, ever-increasing oil trade. In 2009, the total amount of the global oil trade amounted to 2.61 billion tons, whereas global oil consumption was only 3.88 billion tons. Currently, the major oil-exporting regions are the Middle East, countries of the former Soviet Union, and Western Africa, whereas major oil-importing regions include the United States, Europe, Japan, and China.

China became a net oil-importing country in 1993, and the amount it imports has been increasing ever since. From 1995 to 2009, China's crude oil production showed a slight increase of only 40 Mt; by contrast, its oil imports increased by 220 Mt, resulting in its OID increasingly dramatically from 6.6 to 50.7 % (Table 5.1).

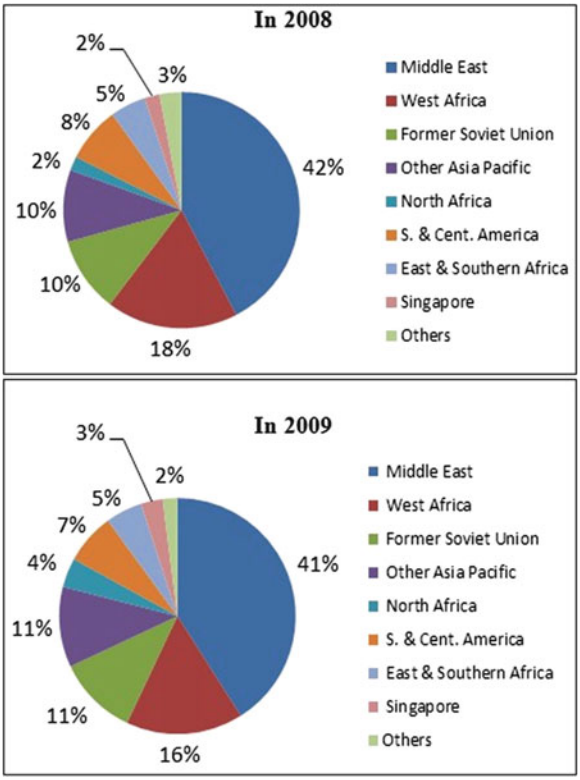

Fig. 5.3 Major regions supplying China's oil imports, 2008 and 2009 (*Data source*: global energy data review by BP 2009, 2010)

In 2009, China's oil imports accounted for 10 % of global oil trade—behind only Europe (26 %) and the United States (22 %) (BP 2010).

China is highly dependent on oil imports from the Middle East and West Africa, most of which is crude oil. However, compared with 2008, oil imports from the former Soviet Union, Asia-Pacific, and other regions increased slightly in 2009, as shown in Fig. 5.3. Meanwhile, the share of crude oil in oil imports decreased from 82 to 80 %, which suggests that China's oil imports are diversifying both in terms of category and channels to ensure energy security.

The SPR is one of the basic measures for ensuring energy security for oil-importing nations. In 2004, China proposed a three-stage plan to establish its national SPR. The first stage involved establishing oil reserve bases in four coastal cities—Dalian, Huangdao, Zhenhai, and Zhoushan; this stage has already been completed. The second stage has also been initiated. The target of the plan is to build a reserve of 85 Mt, which can sustain the country's oil consumption for 100 days, which is slightly higher than the standard set by the IEA. The whole plan is expected to be completed by 2020. As evident in Table 5.1, China's oil stock has been experiencing fast expansion since 2006. According to the National Energy Administration (NEA), national SPR in 2010 exceeded 23 Mt (NEA 2011).

In addition, the Revitalization Plan of the Chemical Industry issued by the State Council in 2009 proposed an increase in the national reserve of petroleum products. The China State Reserve Bureau has long been working on a plan to increase its reserve locations. Previously, its ten reserve locations were mostly in central and east China; the next candidates are Yunnan and Sichuan provinces.

5.2.4 Oil Refining in China

China's petroleum-refining industry is large in terms of overall scale, but it is small with regard to volume per unit. From 2000 to 2009, the scale of China's petroleum-refining industry increased from 269 to 418 Mt/a, which is equivalent to an annual increase of 18 Mt/a; in 2009 alone, there was an increase of 41 Mt/a (BP 2010). In 2009, China's oil-refining volume accounted for 9.5 % of the world total—second to that of the United States (19.5 %). Sinopec and CNPC rank third and ninth globally in terms of their total oil-refining capacity, and they have the greatest capacity in Asia.

Scaling-up has become a major tendency in the global oil-refining industry, and newly built refineries are on average over 10 Mt/a in capacity. In 2009, the average global per unit capacity was 6.57 Mt/a (True and Koottungal 2009). In recent years, the per unit capacity of Sinopec and CNPC has also continuously risen, amounting to 5.7 and 5.4 Mt/a, respectively, in 2009, though this is still far behind the world average. Apart from Sinopec, CNPC, and ten large-scale local refineries, China still has many technically backward small-scale oil refineries (CPN 2010). In 2009, the largest oil refinery in China was Sinopec Zhenhai refinery, which has a capacity of 20 Mt/a, ranking it only 19th in the world that year, behind some large-scale refineries in India and South Korea.

Compared with the world capacity share,[4] the share of catalytic cracking[5] in China's oil-refining technology is high—similar to that of the United States. The share of hydrotreating[6] is also higher than the world average, though the shares

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[4] Capacity share refers to the proportion of the processing capacity in the atmospheric distillation capacity.

[5] FCC is the process of cracking heavy oil into gas, gasoline, diesel oil, and other products under high temperatures and with a catalyst. This is one of the main processes used in heavier oil refineries.

[6] Hydrocracking is the process of cracking heavy oil into gas, gasoline, jet fuel, diesel oil, and other products under heating, high hydrogen pressure, and catalytic action. Its feedstock is usually heavy distilled oil. Its main characteristic is high flexibility in controlling the output rate.

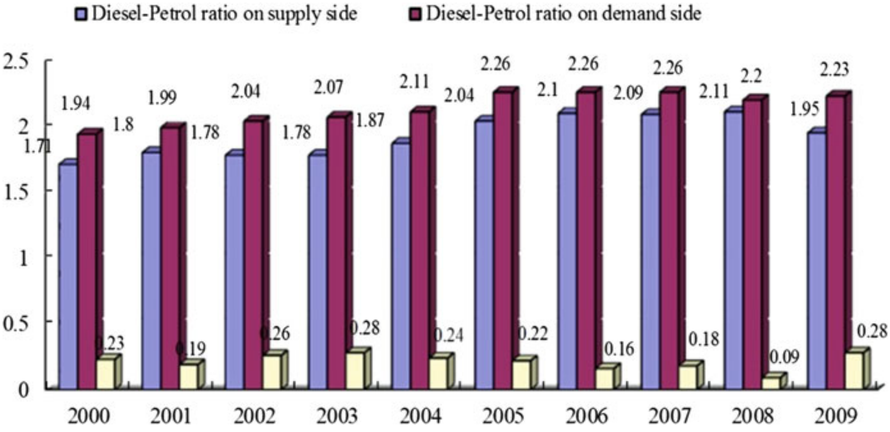

Fig. 5.4 Comparison of supply-side and demand-side diesel-to-gasoline ratios in China (2000–2009) (*Data source*: DESNBS and DGANEA 2010, 2011)

of catalytic reforming[7] and hydrofinishing[8] are substantially lower. This situation can be traced back to the history of China's oil-refining industry. Traditionally, China's oil refineries were mainly configured for domestic, low-sulfur, and heavy crude oil input to produce a variety of output products that lacked an emphasis on low-emission transportation fuels (e.g., low-sulfur diesel and gasoline). Therefore, the share of catalytic cracking is high while that of catalytic reforming is low. To accommodate rising imports of high-sulfur crude oil and booming demands for clean transportation liquid fuels, China has in recent years introduced advanced technology for catalytic cracking, hydrotreating, and coking during the expansion of its oil-refining industry. However, hydrotreating and hydrofinishing, which are needed to improve oil quality and remove impurities, are making slow headway in the industry. To adapt to changes in feedstock and meet the demand for clean transportation fuels, China's oil refineries should continue improving their technology and place greater emphasis on light, clean liquid fuel and lower petroleum consumption per unit output (Walls 2010).

A key challenge is presented by the changing diesel-gasoline ratio on the demand side: owing to flourishing demand for diesel, the diesel-gasoline ratio on the demand side has been increasing; it reached 2.2:1 in 2005 (Fig. 5.4). One major solution to deal with this trend involves increasing the diesel-gasoline ratio in the oil-refining

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[7] Catalytic reforming is the process of transforming light-distillation gasoline fractions (or naphtha) into high-octane-value gasoline under heating, high hydrogen pressure, and catalytic action. Catalytic reforming is a major method for improving the quality of gasoline, and it is commonly employed in modern refineries and petrochemical joint enterprises.

[8] This is the most important method for finishing petroleum products. It refers to removing harmful impurities, such as sulfur, oxygen, and nitrogen, by converting them into the corresponding hydrogen sulfide, water, and ammonia in order to improve the oil products' quality.

Table 5.2 Import and export of China's gasoline and diesel, 2000–2009 (unit, Mt)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Diesel imports	0.52	0.55	0.79	1.12	3.04	0.61	0.81	1.74	6.33	1.93
Diesel exports	0.78	0.47	1.45	2.44	0.87	1.71	1.03	0.93	0.89	4.79
Net import of diesel	−0.26	0.08	−0.66	−1.33	2.17	−1.10	−0.22	0.80	5.44	−2.86
Gasoline imports	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.23	1.99	0.04
Gasoline exports	4.68	5.86	6.30	7.54	5.41	5.60	3.51	4.64	2.03	4.92
Net export of gasoline	4.68	5.86	6.30	7.54	5.41	5.60	3.44	4.42	0.05	4.88

Data source: DESNBS and DGANEA (2010, 2011)

output, but this is hampered by a number of barriers. Since oil-refining units were originally configured to produce certain categories of products and meet a particular diesel-gasoline demand ratio, it is difficult to adjust their output structure.

Both hydrotreating and FCC have certain flexibility regarding adjustment of the output diesel-gasoline ratio. But from an international viewpoint, hydrotreating is more suitable to the output diesel-gasoline ratio, whereas FCC is better for improving the output share of gasoline. In Europe, hydrotreating is mainly carried out to increase diesel output; most US oil refineries adopt low- and medium-pressure hydrotreating, which can simultaneously increase gasoline output and improve diesel quality. In China, the dominant technology is FCC, which is used to further treat heavier fractions after distillation. Following advances with catalysts and related technology, China has managed to achieve a fairly high diesel-to-gasoline ratio, which is higher even than that of Europe. However, owing to the low hydrotreating capacity and already-installed large-scale atmospheric-vacuum catalytic cracking, a diesel-to-gasoline ratio of 2.1:1 is already near the upper technological limit with the facilities currently in service (Sun et al. 2009).

As a result, the imbalance between the supply and demand diesel-to-gasoline ratio is becoming increasingly pronounced (Fig. 5.4), and this has led to oversupply and even export of gasoline (Table 5.2). At the same time, Chinese oil refineries have substantially reduced fuel oil output (Table 5.3); this has resulted in large-scale imports of fuel oil, while refining losses and output of other products have increased accordingly. In 2009, the output ratios of gasoline/diesel and transportation liquid fuels (gasoline, diesel, kerosene) were 58.2 and 62.2 %, respectively, compared with 59.9 and 66.5 % for Europe and 67.8 and 75.3 % for North America (IEA 2011).

5.2.5 *Oil Demand in China*

China is the second-largest oil consumer in the world, second only to the United States. Over the period of 2000–2009, China's oil consumption increased from 226 to 385 Mt, with an annual growth rate of 6.1 %. By 2009, China's oil consumption

Table 5.3 Input and output of China's oil-refining industry, 2000–2009

	Input of crude oil (Mt)	Loss[a] (%)	Gasoline (%)	Kerosene (%)	Diesel (%)	Fuel oil (%)	LPG (%)	Refinery gas (%)	Other products (%)
2000	203.1	3.6	20.4	4.3	34.9	10.1	4.5	3.4	18.9
2001	204.1	3.0	20.4	3.9	36.7	9.1	4.7	3.3	19.0
2002	215.8	4.1	20.0	3.8	35.7	8.6	4.8	3.2	19.7
2003	238.4	4.1	20.1	3.6	35.8	8.4	5.1	3.0	20.0
2004	277.4	4.3	19.0	3.5	35.5	7.3	5.1	3.0	22.3
2005	290.4	4.0	18.7	3.5	38.2	6.1	4.9	3.1	21.5
2006	310.5	4.1	18.0	3.1	37.9	5.7	5.6	3.2	22.3
2007	328.3	3.9	18.0	3.5	37.6	6.0	5.9	3.1	21.9
2008	341.0	4.0	18.6	3.4	39.3	5.1	5.6	3.2	20.7
2009	371.1	4.4	19.7	4.0	38.5	3.6	4.9	3.2	21.6

Data source: DESNBS and DGANEA (2010, 2011)

[a] Including transportation loss and refining loss

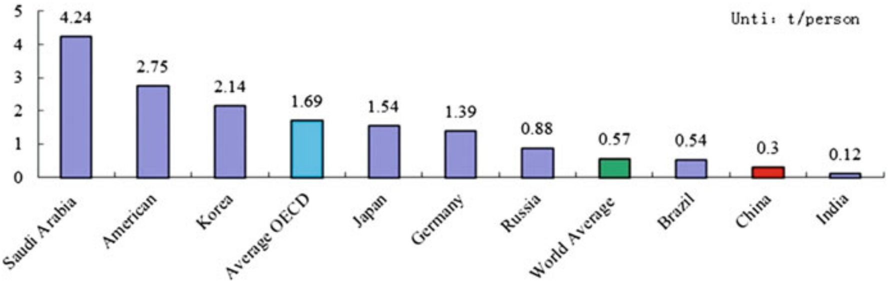

Fig. 5.5 International comparison of oil consumption per capita (2009) (*Data source*: oil data from BP 2010; population data from Population Reference Bureau 2010: 2009 World Population Data Sheet; OECD countries account for 18 % of the global population, according to the OECD factbook 2009)

accounted for 10.4 %[9] of global consumption (21.7 % for the United States). However, the oil consumption per capita per year was only 0.3 tons, which is half the global level and lower than that of most major oil-consuming nations, whose total oil consumption is over 100 Mt (Fig. 5.5).

The issue of oil demand is quite complicated in China because it involves the demand by various sectors for different oil types. Using the same data-processing method (Sidebar 5.1) as that adopted for Fig. 5.1, figures for by-sector oil consumption in 2000, 2003, 2005, 2007, and 2009 can be obtained, as presented in Table 5.4. The main features of China's oil consumption and structure can be summarized as follows:

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[9] According to BP world energy statistics, 2009 Chinese national oil consumption was 404.6 Mt, which was slightly higher than the figure of 384.6 Mt provided by *China Energy Statistics*.

Table 5.4 China's oil consumption by sector (2000, 2003, 2005, 2007, 2009)

	2000		2003		2005		2007		2009		Total increase in 2000–2009	Contribution to total oil demand growth in 2000–2009
Sector	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%[f]
Losses[a]	9.1	4	11.3	4	13.2	4	14.8	4	18.1	5	8.9	6
Own use	42.5	19	51.9	19	58.2	18	63.4	17	66.5	17	24.0	15
Power	16.0	7	19.1	7	20.1	6	13.1	4	8.8	2	−7.2	−5
Agriculture	7.0	3	9.4	3	12.9	4	12.3	3	11.4	3	4.4	3
Agricultural vehicles	–	–	11.0[b]	–	10.0[c]	78[d]	9.1	74	4.4	58	–	
Industry	36.8	16	41.8	15	44.3	14	50.5	14	52.7	14	15.8	10
Chemical	15.1	41	20	48	22.2	50	27.4	54	26.8	51	11.7	74
Mineral	7.8	21	6.8	16	7.8	18	8.4	17	7.3	14	−0.5	−3
Construction	6.5	3	9.7	4	12.0	4	14.9	4	15.6	4	9.1	6
Transportation[e]	89.3	40	109	40	142	44	171	47	185	48	95.3	60
Cars/motorcycles	33.4	37	39.2	36	47.4	33	53.9	32	60.6	33	27.2	28.5
Trucks/buses	34.6	39	43.4	40	60.0	42	72.1	42	83.8	45	49.2	51.7
Trains	2.7	3	3.3	3	4.6	3	5.6	3	6.1	3	3.4	3.5
Planes	5.4	6	7.4	7	9.5	7	11.3	7	13.1	7	7.8	8.2
Ships	13.3	15	15.1	14	20.6	14	27.2	16	21.0	12	7.7	8.1

(continued)

Table 5.4 (continued)

Sector	2000		2003		2005		2007		2009		Total increase in 2000–2009	Contribution to total oil demand growth in 2000–2009
	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%[f]
Commercial	1.5	1	1.6	1	2.1	1	2.5	1	2.3	1	0.8	0
Residential	9.4	4	11.6	4	13.7	4	16.8	5	15.5	4	6.1	4
Urban	7.8	83	9.8	85	10.8	79	13.1	78	11.7	76	3.9	64
Rural	1.6	17	1.8	15	2.9	21	3.7	22	3.8	24	2.2	36
Others	6.2	3	6.0	2	6.6	2	7.4	2	8.5	2	2.3	1
Total[f]	224	100	271	100	325	100	366	100	384	100	159	100

Data source: DESNBS and DGANEA (2010, 2011); Wang (2006, 2007, 2008, 2009, 2010)

[a] Losses include both transportation losses and refinery losses

[b] This data is questionable since the total value for agricultural vehicles exceeds the total diesel consumption in the agricultural sector

[c] Estimated as 10 Mt according to the available data for 2003 (11 Mt) and 2007 (9 Mt)

[d] The percentages in italics are the portion of each subsector within the total oil consumption of the broader sector

[e] The data for the subsectors in transportation before 2007 were estimated assuming that the structure of diesel use was the same as in 2007, when data were available. The gasoline use by motorcycles in 2009 was 1.8 Mt, but no data are available for other years

[f] The proportion of each sector's contribution to the total increase of oil consumption in 2000–2009

1. Transportation is the main propelling factor behind the booming oil consumption. In 2000–2009, the share of transport in total oil consumption increased from 40 to 48 %; increased oil consumption by transportation accounted for 60 % of the total increased oil consumption during this period.
2. Road vehicles, especially diesel vehicles, are the main factor behind the growth in oil demand in the transport sector. Increased diesel consumption by road vehicles accounted for 51.7 % of the total increased oil consumption by transportation; this was followed by gasoline consumption by road vehicles, which accounted for 28.5 %. Kerosene consumption by planes and diesel consumption by trains accounted for 3.5 and 8.2 %, respectively. Diesel and fuel oil consumption by ships accounted for 8.1 %; this consumption began to decrease after 2007.
3. Own use and losses have shown a continual rise. In 2000–2009, own use and losses accounted for a steady annual 22 % of the total oil consumption, and the increase in these areas amounted to 21 % of the total increased oil consumption, second only to that in the transportation sector. This was due to increased losses and transportation losses together with expansion of oil refining and distribution of petroleum products. Over the same period, China's total energy consumption grew at almost 10 % per year, which also drove up own-use oil.
4. Industrial oil consumption has grown steadily and ranks third among the sectors that have contributed to the total increased oil consumption. Consumption in this sector is mainly made up of other products. In 2000–2009, industrial oil consumption accounted for 14–16 % of the total oil consumption, and its increase accounted for 10 % of the total increased oil consumption. Among all sectors, the chemical industry accounts for around half of the total industrial oil consumption. In other oil-intensive industries, such as the mineral industry, oil consumption is generally declining. Overall, it is relatively easy to find alternatives for oil in other industrial sectors; for example, coal and gas can be used as substitutes for oil in providing heat and steam.
5. Oil consumption by the construction industry has experienced a significant increase, and this is notable as a factor behind oil consumption. Although oil consumption by this sector accounted for only 3–4 % of the total oil consumption in 2000–2009, its increase accounted for 6 % of the total increased oil consumption during that period. Construction mainly consumes other products and also some diesel.
6. Oil consumption by the agricultural, commercial, residential, and other sectors has also grown. These sectors accounted for around 10 % of the total oil consumption in 2000–2009, and their increase accounted for around 8 % in the total increased oil consumption over the same period. These sectors mainly consume liquefied petroleum gas (LPG) and diesel. Although rural LPG consumption was less than in urban areas during this period, it grew at a higher rate. In addition, diesel consumption by agricultural vehicles showed a continuous decline, while that by agricultural machines showed a constant rise.
7. Power and heat generation was the only sector that experienced a decline in oil consumption from 2000 to 2009; this was due to restrictive policies on using oil for power and heat generation and also due to its inadequate technology.

Table 5.5 China's oil consumption by oil type, 1996–2009 (unit, Mt)[a]

	Crude oil	Diesel	Gasoline	Kerosene	LPG	Fuel oil	Refinery gas	Other	Total
2000	6.4	65.8	35.0	8.7	13.9	27.4	5.6	36.7	199.5
2001	6.5	69.2	36.0	8.9	14.1	26.9	5.6	36.9	204.1
2002	6.8	74.4	37.5	9.2	16.2	26.8	5.7	43.3	219.9
2003	8.1	81.4	40.7	9.2	17.9	28.8	5.9	48.6	240.6
2004	8.4	95.6	47.0	10.6	20.1	31.3	6.7	61.0	280.6
2005	8.7	106.1	48.5	10.8	20.4	29.5	7.9	60.0	291.9
2006	9.8	115.2	52.4	11.2	22.0	32.7	8.2	64.6	316.1
2007	9.8	122.7	55.2	12.4	23.2	34.6	8.7	72.0	338.6
2008	11.9	133.5	61.5	12.9	21.1	27.6	8.8	69.7	347.0
2009	8.3	136.0	61.7	14.4	21.5	25.3	9.3	80.3	356.9
Total increase	1.9	70.3	26.7	5.7	7.6	−2.1	3.7	43.6	157.4
Contribution rate	1.2 %	44.6 %	17.0 %	3.6 %	4.9 %	−1.3 %	2.4 %	27.7 %	100.0 %

Data source: DESNBS and DGANEA 2010, 2011; Wang 2006, 2007, 2008, 2009, 2010

[a] Own use is not listed in this table; therefore, final consumption may be slightly higher than that indicated in Table 5.4, especially for refinery and other petroleum products

Other power-generation technologies, such as coal, wind, and hydropower, are all superior to oil power in terms of economic and environmental performance. However, oil-based power and heat could not be completely replaced owing to peaking and emergency-power generation needs (Leung 2010).

Seen in terms of final oil consumption by oil type (Table 5.5), in 2000–2009, there was a significant increase in diesel consumption, which accounted for 44.6 % of the total final oil consumption. In recent years, China's diesel consumption has rapidly increased, mainly because of its wide applications, and there has been a simultaneous increase in diesel consumption in a number of areas. A detailed explanation is summarized below and in Table 5.5.

1. Accelerated industrialization and the huge scale of building infrastructure have led to a dramatic increase in demands for freight traffic. Therefore, road, railway, and ship transportation have all exhibited rapid growth in diesel consumption. This is the dominant reason.
2. Accelerated urbanization and motorization have led to an increase in the transportation volume by rail and public transport systems, which mostly consisted of passenger traffic.
3. There has been expansion of energy-intensive industries. Although this segment of diesel consumption may be gradually replaced, oil is still an important energy source for these industries.
4. There has been an increase in military diesel consumption. Although data are lacking in this field, it is estimated that the military sector contributes a great deal to the increase in diesel consumption.

5. With regard to mechanical power, diesel consumption by the construction industry has also risen.
6. Demand for distributed power and heat generation and emergency-power generation has also grown in the residential and commerce sectors.

5.2.6 Oil Prices

International oil transactions are usually priced according to benchmark oil prices in specific regions. There are five major oil spot markets in the world: the United States, Singapore, the Caribbean, the Mediterranean, and northwest Europe. The major oil futures markets are the New York Mercantile Exchange, the London International Oil Exchange, and, emerging in recent years, the Tokyo Commodity Exchange (Wei and Lin 2007).

International oil prices are influenced by many factors, and it is almost impossible to predict future trends. Overall, the international oil prices mainly depend on long-term supply and demand. But at the same time, they are also influenced by such uncertain factors as cyclical fluctuations in the oil industry, world military and political events, and financial speculation. Regarding the international oil price fluctuation that occurred in 2003–2008, studies have shown that this was due to the combined influence of growth in oil demand, lack of investment, shortages in oil-refining capacity, geopolitical uncertainty, the weak dollar, and many other factors (Kesicki 2010). Because of the fall in oil demand caused by large-scale economic recession in developed countries, the 2009 international price of oil (Brent crude price, 2009 dollar exchange rate) fell from US$96.9/barrel in 2009 to $61.7/barrel (BP 2010). However, in 2010 and 2011, the international price of oil rose again, indicating that this price is still volatile.

Although China's oil prices are increasingly in line with world prices, they are still highly dependent on government policy. The most recent oil-pricing policy was the Oil Price Management Measures (trial), which was issued in May 2009 by the NDRC. The main areas of the policy include the following. (1) Crude oil prices should be set independently by enterprises in China with reference to international market prices. (2) Domestic prices of petroleum products should be based on international market prices of crude oil in addition to average domestic manufacturing costs, taxes, and reasonable and appropriate circulation costs and profit margins. To avoid the impact of sharp fluctuations in international market prices on domestic oil prices, when the moving average price in international market changes more than 4 % for 22 consecutive weekdays, domestic gasoline and diesel prices can be adjusted. (3) When the international market price of crude oil falls below $80/barrel, normal processing profit margins should be added to petroleum product prices. If the international market price rises above $80/barrel, processing profit margins should be properly reduced to stabilize oil prices until the zero

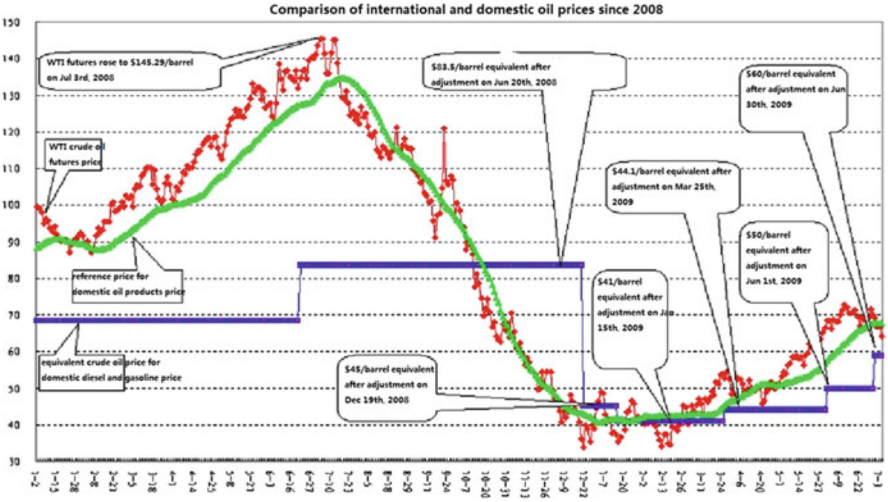

Fig. 5.6 Comparison of domestic and international oil prices, 2008–2009 (*Data source*: http://www.sdpc.gov.cn/xwfb/t20090715_290975.htm)

processing profit margin is reached. If the international market price rises above $130/barrel, taking into account producers' and consumers' interests and the need to maintain a stable national economy, appropriate fiscal policies should be undertaken to guarantee smooth production and supply of petroleum products.

With the intervention of national policy, the impact of international oil price fluctuations on domestic petroleum product prices was smaller in the period of 2008–2009. From the international and domestic oil price comparison in Fig. 5.6, it is clear that China's oil price has been characterized by lagging fluctuation and smaller amplitudes.

Although fuel tax has not been directly imposed in China, it has been indirectly implemented through oil consumption tax. This was achieved through the Notice on Implementing Petroleum Product Prices and Tax Reform promulgated by the State Council in December 2008 (hereinafter, the Notice). The Notice stipulated that gasoline consumption tax would be increased by RMB 0.9/L and diesel by RMB 0.7/L. Together with the original consumption tax, consumption tax on gasoline, naphtha, solvent oil, and lubricating oil would be RMB 1/L, while consumption tax on diesel oil, fuel oil, and kerosene would be RMB 0.8/L.

Compared with other countries, the current price of gasoline in China including tax is higher than in the United States, but lower than in Europe. The reason for this is that the European fuel tax rate is relatively high while that of the United States is low. And China's gasoline price excluding tax is on the same level as in the United States and Europe, the difference being mainly due to the different costs involved in purchasing crude oil (NDRC 2009).

5.2.7 Oil-Related Environmental Policy

Oil-related environmental policies mainly refer to those that control motor vehicle exhaust emissions and vehicle fuel economy policies to improve the efficiency of energy utilization. Fuel quality standards in developed countries have generally become stricter in recent years as a result of global climate changes, and these countries have begun to focus more on controlling GHG emissions. According to an analysis by the IEA (IEA 2010b), to contain temperature rises and keep the global atmosphere CO_2 concentration at 450 parts per million (PPM)[10] or so, the global oil consumption should peak before 2020 and then begin to decline.

According to an analysis by the U.S. National Energy Technology Laboratory (NETL), GHG emissions from crude oil mining and oil refineries account for only a small part of the total emissions. By contrast, emissions in final consumption (mobile sources, such as cars) form the major part, accounting for 80–84 % of the total GHG emissions (NETL 2008). Therefore, for oil GHG mitigation, primary measures should be made to improve the motor vehicle fuel efficiency and emission control standards. The European Union has proposed to set the 2012 GHG emissions for passenger cars at 120 g CO_2/km; in April 2009, it approved a law controlling passenger vehicle CO_2 emissions and fuel consumption. In May 2009, the United States also put forward a policy goal of improving car fuel economy to 36 gal/km (about 7 L/km) by 2016 (Wang 2010).

In China, the problem of conventional pollutants by motor vehicles is still serious. Although in recent years, China has been continuously improving motor vehicle exhaust emission standards, it still has a long way to go compared with developed countries, especially in terms of sulfur content. In June 2008, China began implementing China III emission standards, which are equivalent to Euro III (2000). More stringent standards are implemented in China's big cities, where vehicle exhaust pollution is more severe. For example, Beijing began implementing China IV standards, which are equivalent to Euro IV (2005), in March 2008, and it intends to execute China V standards, which are equivalent to Euro V (2008), by 2012.

According to the plan, China began implementing a gasoline sulfur control standard of 150 PPM in January 2010, and it introduced a diesel sulfur control standard of 350 PPM in July 2011. By 2009, most of the sulfur content of vehicle fuel met only China II standards (equivalent to Euro II), that is, 350 PPM in gasoline and 2,000 PPM in diesel. A survey in 2008 in north China by Zhang et al. showed that 88 % of gasoline had a sulfur content below 350 PPM and 41 % of gasoline had a sulfur content below 150 PPM; only 20.5 % of diesel had a sulfur content below 2,000 PPM and only 17 % of diesel had a sulfur content below 350 PPM (Zhang et al. 2010a). In the United States in 2010, the sulfur content of vehicle diesel was limited to 15 PPM. The European Union reduced the sulfur content in vehicle diesel to 10 PPM in 2009.

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[10] 1 ppm means 1 part per million by volume.

In terms of fuel economy, China in September 2004 began conducting the first and second phases of passenger car fuel economy standards. A recently published study on China's third-stage fuel economy standards proposed that the fuel economy of new passenger cars should be improved to 7 L/km by 2015 and 5 L/km by 2020 (Wang et al. 2010).

China has no mandatory obligation to cut GHG emissions. However, at the 2009 United Nations climate change conference held in Copenhagen, China promised to decrease its CO_2 emissions intensity by 40–45 % from 2005 to 2020, and it has begun to focus on executing this. This policy will strongly promote the efficient use of oil and the development of low-carbon fuels as alternatives to fuel oil.

5.3 Future Challenges and Coping Strategies

5.3.1 Literature Review

Before conducting our analysis, we reviewed related studies on China's future development of oil that had been conducted since 2000. These studies mainly focused on the demand for oil and liquid fuels, the oil demand of road vehicles, domestic oil production, and energy security; however, few discussed an integrated development strategy for oil supply, demand, and security. Therefore, though these studies are an important source of information, they do not provide a complete view of the future development of oil in China owing to the lack of an integrated approach.

5.3.1.1 Future Demand for Oil and Liquid Fuels

Because oil (petroleum and petroleum-derived fuels) may be replaced by liquid fuels from other primary energy sources, some studies have focused on the demand for liquid fuels other than oil. The forecast results of future demand for oil and liquid fuels are normally expressed as tons of oil or tons of oil equivalent. Some international organizations, such as the IEA, OPEC, and U.S. Energy Information Administration (EIA), made predictions for the future demand for oil and liquid fuels in China, as listed in Table 5.6. On the whole, the forecast result by OPEC was higher, that of IEA was lower, and that of EIA was intermediate between the other two.

Compared with the reports of 2009, the forecasts of OPEC and EIA in 2010 predicted higher demand. However, the result of IEA was more conservative in light of China's policy for reducing GHG emissions. In the EIA report, uncertainties with respect to the international price of oil were a main influencing factor for future oil demand in China.

Table 5.6 Forecasts of demand for liquid fuels in China by international organizations (unit, Mt)

Data source	2010	2015	2020	2025	2030	2035
OPEC (2009)	413	518	612	702	792	–
IEA (2009)	–	490	557	646	758	–
EIA (2009)	423	498	602	687	762	–
Average	–	502	590	687	758	–
OPEC (2010)	433	543	652	747	832	–
IEA (2010b)	–	528	583	647	712	762
EIA (2010)		515	598	699	793	873
Average	–	529	610	700	780	–

Note: The results in this table are all from reference scenarios

However, some Western scholars believe that these results are still too conservative. For example, Nel and Cooper (2008) plotted curves for China's smallest increase in oil demand per capita in the light of international experience, and they made predictions based on GDP, population data, and the data presented in IEA's "World Energy Outlook 2006." The result showed that, according to the smallest-increase curve, China's oil demand may reach 1.43 billion tons in 2030.

Because of considerations of energy security, domestic oil demand forecasts are normally conservative. A recent study conducted by the Chinese Academy of Engineering determined that China's oil demand would be 500–600 million tons in 2020, 600–700 million tons in 2030, and 700–800 million tons in 2050 (CAE 2011a).

In addition, foreign studies have all recognized that the rapid increase in oil demand in transportation (especially road transport) would be the main propelling force for demand in liquid fuels and that the future demand for diesel would be greater than that for gasoline. Taking IEA and EIA (IEA 2009; EIA 2010) as examples, results showed that 80 % of the increased demand for liquid fuels in China from 2007 to 2030 would be caused by rising demand from the transport sector. The IEA's study about China showed that the rapid increase in the number of passenger and freight vehicles would be the leading cause of swift growth in demand for liquid fuels (IEA 2007). Cambridge Energy Research Associates also conducted a study on China in 2008. The results showed that the future speed of growth in diesel demand would be much greater than that for gasoline; it was also determined that the diesel-gasoline ratio would be 3.9:1 in 2030.

5.3.1.2 Future Oil Demand by Road Vehicles

Research results regarding future oil demand by road vehicles in China differ quite significantly. The main reason for this is that different studies make different assumptions about the future vehicle population, use, fuel economy, and development of alternative fuels. He et al. (2005) made a scenario analysis of oil consumption and carbon emission of Chinese road vehicles up to 2030. Their results showed that oil consumption by such vehicles would rapidly increase and that vehicle fuel economy improvement was absolutely critical to saving oil and reducing carbon emissions. By improving fuel economy, oil consumption by road vehicles could be reduced from 360 to 280 Mt. Wang et al. (2010) estimated that 39.2 Mt of oil could be saved if the third-phase fuel economy standard could be passed and implemented.

A study by Zhang et al. (2010b) determined that the development of biofuels could considerably lower oil consumption by road vehicles. Under the business-as-usual (BAU) scenario, oil consumption by transport will amount to 992 Mt by 2030. Among that, 392 Mt could be saved by promoting bioethanol gasoline, 135 Mt by improving fuel economy, and 204 Mt by popularizing biodiesel. Ou et al. (2010) designed six scenarios of oil consumption by Chinese road vehicles up to 2050; the scenarios added such new technologies as coal-derived liquid fuels, electrical vehicles, and carbon capture and storage. As a result, under the BAU scenario, oil consumption will be 412 Mt in 2050, but that figure could be reduced to 165 Mt if all possible oil-saving and oil-substitution technologies are employed.

5.3.1.3 Future Production of Crude Oil

Based on oil peak theory, many Chinese and international scholars have proposed oil peak prediction models, which were used to forecast Chinese crude oil production and reserves. Among them, three have been widely used: the Hubbert model, Weng model, and HCZ model (Feng et al. 2007). Comparing the results of these models, the forecast results are mostly not positive: the forecast oil peak would be reached at the latest by 2020. In a recent study, Feng et al. (2008) predicted that the Chinese oil peak would occur in 2011 in the absence of substantial technological development.

However, those studies did not properly consider improvements in exploration and extraction technology regarding conventional and unconventional resources. The Chinese Academy of Engineering (CAE) proposed in 2003 that the future trend of annual crude oil production in China would be as follows: oil peak production would become stable at 180–200 Mt; China has already entered the peak period, and this peak period may last until after 2035 (CAE 2003). In 2011, CAE suggested that crude oil production in China should and could be maintained at 180–200 Mt up to 2050 (CAE 2011a).

Recently, international studies have been increasingly influenced by the results of studies conducted in China. The IEA predicted in 2007 that the Chinese oil peak would be 194 Mt before 2015; thereafter, crude production would decline quickly to 130 Mt by 2030 (IEA 2007). However, in 2008, the IEA adjusted that prediction according to changes in circumstances in China, whereby China would maintain oil production at 200 Mt up to 2030 (IEA 2008).

5.3.1.4 Energy Security Issues

In a previous study by the present authors (Ma et al. 2011), it was pointed out that national energy security is more complex than the measures currently

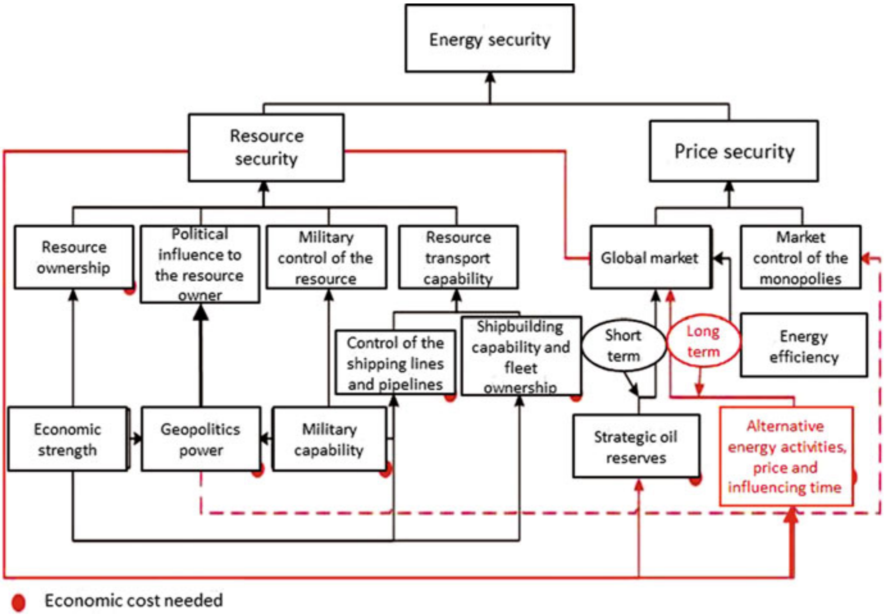

Fig. 5.7 Proposed framework for an energy security system for China

implemented by China would tend to suggest. Those measures include strategies to encourage domestic oil companies to become more deeply involved in global markets, setting up SPR, diversifying oil imports, and developing alternative fuels. The national energy security system is a huge system that involves many factors and players, including the military, politics, the economy, diplomacy, and technology. Implementing some of those factors demands high costs. That study proposed a national energy security system as illustrated in Fig. 5.7, where the arrows represent the decisive sources and influencing issues, and the red arrows and red points signify that costs are required.

In that figure, oil security includes resource security and price security, which are closely correlated with each other. For a country, resource security mainly depends on direct ownership of domestic and foreign resources as well as the political influence, military control, and resource transport capabilities of the resources owner. Price security is influenced by the supply–demand balance of international markets and control of the oil price by international oil monopolies. With a certain demand, the global supply–demand market is influenced by resource security, SPR amount, energy efficiency, and alternative-energy amount. The international oil monopolies pursue maximum economic profit, but their attempts and behavior to control market prices are under the constraints of geopolitics; overly high prices may lead to sluggish demand and long-term economic interest losses.

Some scholars have investigated the measures that could be adopted for China's energy security. Feng and Mu (2010) suggested that a proactive strategy in Africa faced economic and diplomatic problems in addition to cultural challenges. Zhang et al. (2009) conducted research into the optimal scale of SPR in China and concluded that the amount should be 44 Mt in 2017 under the BAU scenario. Zhang et al. also determined that if the oil supply becomes at high risk, the reserve should be increased to 75 Mt. Wu et al. (2010) proposed that the risk of importing product oil is smaller than that of importing crude oil.

Recently, research into energy security has involved the interactions among Chinese oil demand, international oil prices, and the US dollar exchange rate. Skeer and Wang (2007) examined the influence between Chinese oil demand and oil prices. Their results showed that the demand for Chinese oil-based liquid fuel would sharply grow and push up the oil price, thereby promoting the development of energy security measures, such as oil exploitation, oil diversification, and developing alternative fuels. Du et al. (2010) pointed out that although Chinese economic development was more closely linked with oil prices than ever before, China still did not have sufficient power to influence the international oil price. Benassy-Quere et al. (2007) showed that the rise of China in the world oil and international exchange markets would heavily influence the relationship between the world oil price and the US dollar exchange rate. Though the fluctuation in international oil prices has not retarded the economic development of China in the past, international experience suggests that that could happen in the future.

5.3.2 Scenario Analysis of Chinese Oil Consumption

Depending on China’s oil development, the demand for liquid fuels will continue to show rapid growth if current trends continue. Because it will be difficult to bring about an increase in domestic crude oil production, oil imports will continue to grow and energy security risks will thereby increase. China may therefore control its total oil consumption in the future to keep it within 600–700 Mt per year to ensure the safety of its energy supply (CAE 2011a). To realize such a target, China faces various choices in its oil-conservation strategies, and these will have important influences on vehicle diesel and gasoline consumption.

The following analysis is based on different oil-consumption control targets and oil-conservation methods under three possible scenarios up to 2030:

1. Linear Extrapolation Scenario: a continuation of the historical linear increase trend of 2000–2009.
2. Total Consumption Control Scenario A: oil consumption is kept to under 700 Mt, and there is an emphasis on oil conservation in the nontransport sector.
3. Total Consumption Control Scenario B: based on the second scenario, oil conservation is further enhanced in the transport sector, and alternative fuels are developed to keep oil consumption under 600 Mt.

Table 5.7 Oil consumption in China in 2020 by sector and by oil type under the Linear Extrapolation Scenario (unit, Mt)

	Crude	Gasoline	Kerosene	Diesel	Fuel oil	Liquid gas	Refinery gas	Other oil production	Gross oil product
Loss	29.1								29.1
Own use	7.5			1.9		0.5	13.5	74.2	97.5
Power and heat				0.6			3.8	3.7	8.1
Agriculture				16.7		0.1			16.8
Factories	3.4	0.3		18.9	6.4	4.9	0.4	37.8	72.0
Buildings		0.2	0.2	4.4	0.3			21.6	26.7
Transportation		93.8	22.7	166.4	17.4	1.0			301.3
Commerce		0.1	0.5	1.9	0.0	0.7			3.2
Residential				0.6		22.7			23.2
Other				11.3		0.8		0.3	12.4
Gross	40.0	94.4	23.3	222.5	24.1	30.8	17.7	137.6	590.5

Table 5.8 Oil consumption in China in 2030 by sector and by oil type under the Linear Extrapolation Scenario (unit, Mt)

	Crude	Gasoline	Kerosene	Diesel	Fuel oil	Liquid gas	Refinery gas	Other oil production	Gross oil product
Loss	39.1								39.1
Own use	8.6			0.8			18.0	101.4	128.8
Power and heat							5.1	5.3	10.4
Agriculture				21.5		0.1			21.7
Factories	4.6	0.4		24.8	3.1	6.4		50.7	89.9
Buildings		0.3	0.3	5.9	0.4			30.0	36.8
Transportation		124.0	31.3	228.8	21.9	1.5			407.4
Commerce		0.2	0.6	2.5		0.8			4.1
Residential				0.9		29.9			30.8
Other				14.8		1.1		0.5	16.4
Gross	52.4	124.8	32.2	300.0	25.3	39.7	23.1	187.8	785.2

5.3.2.1 Linear Extrapolation Scenario

By assuming that oil consumption by sector and by oil type will continue the same trend as existed from 2000 to 2009, we can derive the oil consumption for 2030 and 2050 by linear extrapolation, as presented in Tables 5.7 and 5.8.

Under this scenario, Chinese oil consumption will amount to 591 Mt in 2020 and 785 Mt in 2030. With the new increased demand for oil, transport will account for 56 %, own use for 16 %, industry for 9 %, and loss for 5 %. In addition, because of the increase in oil demand in the nontransport sector, growth in demand for diesel demand will be larger than that for gasoline (Table 5.9), and the diesel-gasoline ratio will further increase to 2.36:1 in 2020 and 2.4:1 in 2030. Meanwhile, the rapid growth of other oil products may lead to tension in the supply of chemical materials.

Table 5.9 Structure of oil product demand up to 2030 under the Linear Extrapolation Scenario

	Crude (%)	Gasoline (%)	Kerosene (%)	Diesel (%)	Fuel oil (%)	Liquid gas (%)	Refinery gas (%)	Other oil production (%)
2009	17.3	4.0	38.5	7.9	6.0	3.3	23.0	100
2020	17.2	4.2	40.4	4.4	5.6	3.2	25.0	100
2030	17.0	4.4	40.9	3.5	5.4	3.2	25.6	100

Using linear extrapolation, we also can obtain the vehicle fuel consumption of diesel and gasoline under this scenario. In 2020, vehicle diesel and gasoline consumption will be 144 and 94 Mt, respectively, which will account for 40 % of the gross oil consumption and 46 % of the new increased oil consumption. In 2030, diesel and gasoline consumption will amount to 199 and 124 Mt, respectively, and the proportion of gross oil and increased oil will be 41 and 45 %.

5.3.2.2 Total Consumption Control Scenario A

Simple linear extrapolation using historical trends has its limitations. First, China is currently in a period of dynamic development: there are many uncertainties regarding the future, and so it is difficult to make forecasts using linear extrapolation. Second, the influence of policy needs to be considered. Policies with respect to energy conservation and energy security will be increasingly strict. For example, according to NEA (2011), Chinese oil consumption in 2010 showed a 12.3 % increase above the 2009 level; this was quite large given that the average increase rate from 2000 to 2009 was 6.1 %. As another example, from 2007 to 2009, oil demand in many nontransport areas, such as agricultural, commercial, residential, and energy-intensive industrial sectors, showed a decline; this was the reverse of the above trend and was caused by the influence of energy saving and development of alternative fuels.

Under Total Consumption Control Scenario A, we assume that future policies will be adjusted as appropriate and achievements will be made in some foreseeable problems, including the following: (1) restricting total oil consumption to no more than 700 Mt in 2030; (2) promoting oil conservation and developing alternative fuels in nontransport sectors, especially diesel conservation and diesel alternatives; and (3) preferential supply to the transport sector, especially liquid fuels to meet the demands of passenger transport (e.g., cars and planes); this is because the demand for liquid fuels by this sector will also be limited by restrictions on total oil consumption. In addition, changes in oil demand will have to conform with China's macroeconomic trends in the future. It is expected that the development of industrialization will accelerate up until 2020, that the trend of large-scale construction of the infrastructure will continue, and that thereafter all areas will show stable development. Up to 2030, urbanization and motorization will continue to show fast growth.

Regarding total oil consumption, the assumption is that up to 2020 consumption will maintain its rapid growth to 600 Mt, that is, intermediate between the level in the linear extrapolation scenario (590 Mt) and the average prediction made by international organizations (610 Mt), as indicated in Table 5.6. If energy saving and energy security policies continue to be successful up to 2030, the total amount of oil consumed will be effectively maintained under 700 Mt. On this basis and following the historical trends from 2000 to 2009, we can make assumptions about the changing proportion of oil consumption in China by sector and oil type up to 2030:

1. Oil loss: up to 2020 China will be busily expanding refinery construction, therefore, it may be difficult to achieve a significant drop in oil loss. Subsequently, because expansion of refineries will slow down, we assume that oil loss will be restricted to 4 % after 2020 and fall to 3 % by 2030.
2. Own use: the average annual own-use rate fell 1.11 % from 2000 to 2009. In light of this trend, the own-use rate will fall to 15 % by 2020 and 14 % by 2030 (though the demand for own-use oil for chemical raw materials will increase, natural gas chemicals, coal chemicals, and even the import of chemical materials can replace part of the demand). With regard to oil consumption by oil type, during 2000–2009, the proportions of other products and refinery gas rose significantly; the remaining types all showed a decline; and crude oil maintained a high proportion. Thus, we assume that in 2020, the composition of oil products will be as follows: other products, 78 %; refinery gas, 18 %; and crude oil, 4 %. In 2030, we assume that other products will account for 80 % and refinery gas for 20 %.
3. Power and heat generation: we assume that this proportion will fall to 1 % in 2020, and thereafter the level will remain unchanged since oil power cannot completely disappear. We assume that the composition will maintain the recent diverse proportional trend: 25 % diesel, 25 % fuel oil, 25 % refinery gas, and 25 % other products.
4. Agriculture: agricultural diesel consumption declined after 2005. We assume that this proportion will fall to 2 % in 2020 and 1 % in 2030; we further assume that all consumption in this sector will be diesel.
5. Industry: because alternative fuels have great potential, we assume that oil consumption by industry will gradually decline in the same manner as the trend from 2000 to 2009: the fall will be to 11 % in 2020 and 9 % in 2030. The general trend among industrial oil consumption from 2000 to 2009 was as follows: consumption of other petroleum products rose significantly; consumption of fuel oil was clearly reduced; and LPG and diesel consumption increased a little. Therefore, we assume that the composition of industry oil products will be as follows: in 2020—60 % other petroleum products, 25 % diesel, 10 % fuel oil, and 5 % LPG; in 2030—70 % other petroleum products, 15 % diesel, 10 % fuel oil, and 5 % LPG.
6. Construction: considering that large-scale infrastructure building will be mostly completed close to 2020, we assume that oil consumption by the construction

industry will be maintained at 4 % up to that year and then fall to 3 % by 2030. The composition of that consumption will remain as at present: 80 % other products and 20 % diesel.

7. Commerce and other: we assume that the proportion will remain constant until 2030: 1 % commerce and 2 % other consumption. The composition of oil consumption by commerce is assumed to be 75 % diesel and 25 % LPG up to 2020. In 2030, all consumption by commerce will be diesel. Consumption of oil by the other sector will be diesel.
8. Residential: after 2007, the consumption of LPG by the residential sector presented a downward trend, especially in urban areas; in rural areas, it showed almost no change. The main reason for this was that natural gas gradually replaced LPG. Therefore, we assume that the proportion of oil consumption by the residential sector will fall to 3 % in 2020 and 2 % in 2030; we assume that all that consumption will be LPG.
9. Transportation: the remaining oil consumption is all for transportation, and that fraction will be 57 % in 2020 and 64 % in 2030. With respect to oil type, the diesel-gasoline ratio showed an ongoing rise from 2003 to 2009, the LPG ratio evidenced no significant change, the proportion of gasoline initially declined but then rose, and the proportion of fuel oil first increased before dropping. We assume that the liquid fuel demand by road passenger transportation and aviation will persist, the rising trend of road-freight diesel demand could slow down after 2020, railway diesel consumption will diminish with improvements in electrification, and LPG and fuel oil demand will not increase. Considering all these factors, the composition of oil product consumption (except LPG) by the transport sector is assumed to be as follows: in 2020—55 % diesel, 35 % gasoline, 8 % kerosene, and 2 % fuel oil; in 2030—50 % diesel, 40 % gasoline, and 10 % kerosene.

From the above rough analysis, we can obtain figures for the total oil consumption in 2020 and 2030 according to sector and oil type, as presented in Tables 5.10 and 5.11. The transport sector will account for 83 % of oil-demand growth in 2009–2030, and the rest will be accounted for by own use (10 %), industry (4 %), construction (2 %), other (2 %), commerce (1.5 %), and loss (1 %); the power and heat (–1 %), agriculture (–2 %), and residential (–0.5 %) sectors will show a decrease.

Under Total Consumption Control Scenario A, the changes in oil consumption according to oil type in 2009–2030 appear in Fig. 5.8. The demand for diesel, gasoline, kerosene, and other transportation fuels all exhibit a rapid rise; the demand for refinery gas and other products likewise shows a significant growth, whereas demand for fuel oil and LPG decreases. After 2020, the growth in demand for diesel and other products will decelerate.

Table 5.12 presents the consumption of oil products in China up to 2030 excluding oil loss and own use. It is evident that the problem of the imbalance in the diesel-gasoline ratio will be largely solved during that period. Owing to reduced diesel consumption by industry and in energy supply, the diesel-gasoline ratio will

Table 5.10 Oil consumption in China in 2020 according to sector and oil type under Total Consumption Control Scenario A (unit, Mt)

	Crude	Gasoline	Kerosene	Diesel	Fuel oil	Liquid gas	Refinery gas	Other oil production	Gross oil product
Loss	24								24
Own use	3.6						16.2	70.2	90
Power and heat		1.5			1.5		1.5	1.5	6
Agriculture		12.0							12
Factories		16.5			6.6	3.3		39.6	66
Buildings		4.8						19.2	24
Transportation		188.1	119.7	27.4	6.8				342
Commerce		4.5				1.5			6
Residential						18			18
Other		12							12
Gross	27.6	239.4	119.7	27.4	14.9	22.8	17.7	130.5	600

Table 5.11 Oil consumption in China in 2030 according to sector and oil type under Total Consumption Control Scenario A (unit, Mt)

	Crude	Gasoline	Kerosene	Diesel	Fuel oil	Liquid gas	Refinery gas	Other oil production	Gross oil product
Loss	21								21
Own use							19.6	78.4	98
Power and heat		1.75			1.75		1.75	1.75	7
Agriculture		7							7
Factories		9.45			6.3	3.15		44.1	63
Buildings		4.20						16.8	21
Transportation		224	179.2	44.8					448
Commerce		7							7
Residential						14			14
Other		14							14
Gross	21	267.4	179.2	44.80	8.05	17.15	21.35	141.05	700

drop to 2:1 on the demand side by 2020; thereafter, because industrialization will tend to stabilize and the demand for freight transportation will slowly increase, the diesel-gasoline ratio will be further reduced to 1.49:1 by 2030.

Considering the growth trends in railway electrification and the reduction in oil consumption by ships, most of the future diesel consumption will be accounted for by road transportation. We assume that in 2020, 90 % of transportation diesel will be used for road vehicles and that that will rise to 95 % by 2030. We can estimate the supply of vehicle diesel and gasoline under Total Consumption Control Scenario A: in 2020, vehicle fuel will amount to 120 Mt of gasoline and 169 Mt of diesel, which will account for 48 % of the total oil consumption and 67 % of the consumption growth 2009–2020; in 2030, vehicle fuel will amount to 179 Mt of gasoline and 213 Mt of diesel, which will account for 56 % of the total oil consumption and 78 % of the consumption growth during 2009 to 2030. All these forecasts are greater than

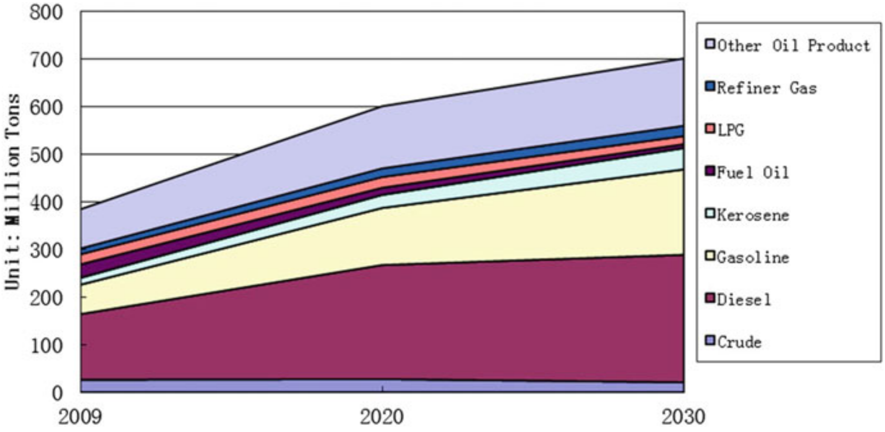

Fig. 5.8 Oil consumption in China according to by oil type under Total Consumption Control Scenario A (2009–2030)

Table 5.12 Consumption of oil products in China up to 2030 under Total Consumption Control Scenario A

Year	Gasoline (%)	Kerosene (%)	Diesel (%)	Fuel oil (%)	LPG (%)	Refinery gas (%)	Other oil products (%)	Total (%)
2009	17.3	4.0	38.5	7.9	6.0	3.3	23.0	100
2020	20.9	4.8	41.8	2.6	4.0	3.1	22.8	100
2030	26.4	6.6	39.4	1.2	2.5	3.1	20.8	100

those predicted under the Linear Extrapolation Scenario. This means that despite the reduction in the total oil supply, oil savings in the nontransport sectors could result in more gasoline and diesel for road vehicles.

5.3.2.3 Total Consumption Control Scenario B

Under Total Consumption Control Scenario B, oil demand will be confined to less than 600 Mt by 2030; this demands a further reduction by 100 Mt in the oil consumption used as the basis for Total Consumption Control Scenario A. Since Total Consumption Control Scenario A has fully accounted for the oil-saving potential in the nontransport sector, the 100-Mt reduction in oil demand will largely have to derive from transportation and mainly through energy saving and alternative fuels for road vehicles.

Energy saving and alternative fuels for road vehicles will be examined in detail in other chapters of this book. This chapter will therefore just briefly discuss the methods used in creating Total Consumption Control Scenario B; instead of carrying out quantitative analysis, views and opinions will be presented here.

Total oil demand by transportation can be expressed using the following formula:

$$O = M \cdot \sum_{\text{modes}} \sum_{\text{fleets}} A_m S_{m,\mathrm{f}} I_{m,\mathrm{f}} F_{m,\mathrm{f}} \tag{5.1}$$

where O signifies the oil demand—unit, tons of oil equivalent (toe); M signifies the transport demand—the unit for freight transport is tons · km and that for passenger transport is person · km; A_m signifies the share of a certain transport mode m (such as road, railway, water, and aviation); $S_{m,\mathrm{f}}$ signifies the share of a certain kind of transport fleet in the mth kind of transport mode (such as in road traffic, vehicles can be classed by weight or application); $I_{m,\mathrm{f}}$ signifies the average fuel efficiency of a certain kind of transport fleet in the mth transport mode—the unit is toe/(person · km) or toe/(t · km); and $F_{m,\mathrm{f}}$ signifies the supply efficiency from crude oil to the final transportation of oil products.

From this, we can examine ways of achieving traffic oil savings.

1. *Guiding Traffic Demand*
   The reduction in total traffic demand M can fundamentally reduce the oil demand by the transport sector. With freight transport, traffic demand can be reduced by optimization of the industrial structure and logistics operations. For example, coal transportation currently accounts for 40 % of rail transport capacity and a significant proportion of road transport capacity. Instead of transporting raw coal over a long distance, if coal conversion were carried out near coal mines (such as in coal power generation and production of coal chemicals), considerable reductions in transport demand for electricity and chemicals would be achieved. The traffic demand by urban residents could be reduced by optimizing urban land function, balancing the spatial distribution of working and living environments, and using information transmission instead of physical travel (Lu et al. 2008).

2. *Optimizing a Multilevel Transport Structure*
   The unit transport energy consumption by various kinds of transport modes is very different. For example, according to 2005 statistics, the unit transportation energy consumption of air transport was eight times greater than that of road transport; the average unit road transport energy consumption was 18 times that of rail transport and 22 times that of water transport (CAE 2011b). In urban passenger transport, the unit rail transport energy consumption is far lower than that of road traffic. Therefore, improving the proportion of rail and waterway traffic and developing urban rail traffic will help reduce the consumption of oil by transport.

   Among specific transport modes, there are great differences in the unit transportation energy consumption of different kinds of vehicles. For example, the unit transport energy consumption of buses is far lower than that of cars. The weight and emissions of cars can influence unit transport energy consumption. Therefore, promoting the use of public transport and encouraging the use of small cars will benefit energy saving by road transport.

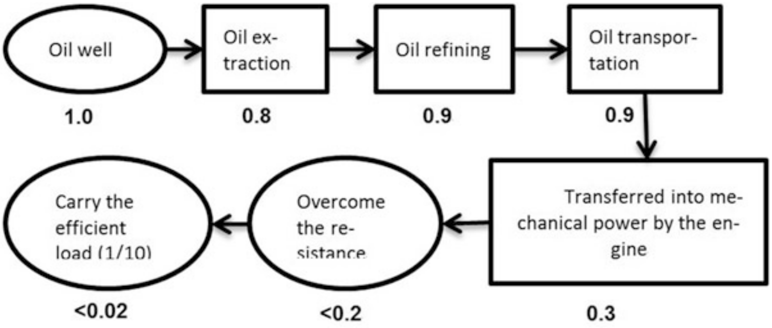

Fig. 5.9 Magnification effect of end-use energy saving by automobiles. *Note*: The rectangles represent the efficiency of a single sector; the ovals represent accumulated efficiency

3. *Improving the Efficiency of Vehicles*
   There is a huge potential for making cars more efficient in terms of energy. According to rough estimates, only 30 % of the energy of a gasoline car is transformed into mechanical energy and transferred to the wheels. The remaining 70 % is lost during the transmission system: lack of engine efficiency, energy consumption by environmental protection facilities, and loss of mechanical transmission efficiency during torque transmission to the wheels (Lovins et al. 2004). Since two-thirds to three-fourths of the energy loss is related to the car weight during application, the energy-saving potential of lightweight materials is enormous. Another effective measure is developing more hybrid cars.

   In addition, the energy efficiency of cars is also related to such factors as road conditions, load rate, and driver habits. Measures toward improving transport management and optimizing transport scheduling, encouraging car pooling, avoiding idle load and flameout, and improving traffic management have great potential for energy saving.

4. *Reduce Energy Loss in the Fuel Supply*
   Improving energy efficiency in the areas of crude oil extraction, transportation, refining, and distribution will help reduce the oil demand by the transport sector. However, there is greater potential for energy saving by the end user, such as the measures cited above: reducing traffic demand, optimizing the transport structure, and improving the energy efficiency of vehicles.

   According to preliminary estimates, in the well-to-wheel supply chain from oil exploitation to consumption by the vehicle, after oil extraction, refining, and distribution, only about two-thirds of the energy is effectively delivered to the motor vehicle fuel tanks. Ultimately, only one-fifth of the energy of the oil resource is effectively utilized; 90 % of this one-fifth energy is used to carry the vehicle's own weight and less than 10 % is used to carry the payload (passengers). Therefore, after various rounds of conversions and losses, only about 1/50 of the energy of the petroleum is effectively used, as shown in Fig. 5.9 (Ni et al. 2009). Therefore, for motor vehicles, the scale effect (magnification effect) of final energy saving can be several times and even dozens of times the energy saving that can be achieved on the supply side. For energy saving by transportation, end-use energy saving should be prioritized. At the same time, terminal energy saving often faces the problem that at this stage, change is more difficult to implement.

In addition to transportation energy saving, another effective way to reduce traffic oil consumption is developing different kinds of alternative fuels, especially those for vehicles. However, it should be noted that the various kinds of alternative fuels for vehicles are still at an early stage of development. They all face problems regarding benefits and costs: they provide the positive benefit of reducing oil demand, though they also incur other negative costs or risks. For example, coal-derived fuel has low efficiency and produces additional carbon emissions, biofuels demand the collection of raw materials and the use of land and water resources, and the electric car technology faces innovation risks. Therefore, the development of alternative fuels for vehicles should not in general take priority over traffic energy saving. The development scale of alternative fuels for vehicles has to be carefully analyzed in terms of costs and benefits instead of simply attempting to introduce the fuels as quickly and on as great a scale as possible.

Considering medium- to long-term technological developments and economic feasibility toward replacing almost 100 Mt of oil with alternative fuels, coal-derived fuels and natural gas, which belong to the realm of fossil energy, may be more realistic choices. At the same time, technical breakthroughs and innovations with electric cars and the second generation of biofuels should be accelerated. After all, they represent the development direction of the future (Ma et al. 2009).

In addition, current automotive alternative fuels are mainly aimed at providing substitutes for gasoline; there are fewer choices for diesel alternative technology. Therefore, the large-scale development of alternative fuels for vehicles may address the imbalance in the diesel-gasoline ratio, which was dealt with in Total Consumption Control Scenario A. This question demands further study and examination.

5.3.3 Energy Security Constraints and Oil Gap

With China's present energy security policy, there are no clear constraint indicators, such as lowering the energy intensity (energy consumption per unit of GDP) and carbon emission intensity (CO_2 emissions per unit of GDP) in energy-conservation and emission-reduction policies (Xinhua Net 2011). Different energy security constraints will have a great effect on China's total oil supply and will further affect the supply of vehicle gasoline and diesel. Under strict energy security constraints, the future oil supply of China may be lower than the demand and create a gap in the oil demand—an oil gap—that requires additional alternative fuels if it is to be filled.

Table 5.13 Six scenarios for China's energy security constraints and the oil gap

	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	Scenario F
Energy security constraint	None	SOT 15 %	OID 70 %	SOT 12 %	OID 65 %	OID 60 %
Crude oil production (Mt)	200	200	200	200	200	200
Maximum oil import (Mt)	No limit	493	467	394	371	300
Oil gap in Scenario I (Mt)	No	92	118	191	214	285
Oil gap in Scenario II (Mt)	No	7	33	106	129	200
Oil gap in Scenario III (Mt)	No	No	No	6	29	100

*In Scenario A, the SOT of Scenarios I, II, and III will be about 18, 15, and 12 %, respectively, and the OID of Scenarios I, II, and III will be about 75, 71, and 67 %

*Once one energy constraint has been decided, the others can be calculated based on the basic setting. For example, the OID of Scenario B and Scenario D is about 71 and 66 %, respectively, and the SOT of Scenario C, Scenario E, and Scenario F is about 14, 11, and 9 %

*SOT signifies share of oil trade; OID signifies oil import dependency

To quantitatively examine the relationship between different energy security constraints and the oil gap, we designed six possible oil supply-and-demand scenarios for 2030, as indicated in Table 5.13. The design steps and the main considerations of these scenarios are detailed below.

5.3.3.1 Basic Boundary Conditions

For domestic oil production, stable domestic oil production of 200 Mt is assumed for 2030. For domestic oil demand, reference is made to the three 2030 scenarios presented in Sect. 5.3.2. For international oil trade, for consistency with the rest of this chapter, we use the predictions of OPEC (2010): in 2030, the global oil trade will be 3.287 billion tons.

5.3.3.2 No Energy Security Constraint Scenario (Scenario A)

Under the situation of no energy security constraints, the gap between domestic oil demand and production will be completely met by oil imports: Total Consumption Control Scenario B requires 400 Mt, Total Consumption Control Scenario A requires 500 Mt, and the Linear Extrapolation Scenario requires 585 Mt.

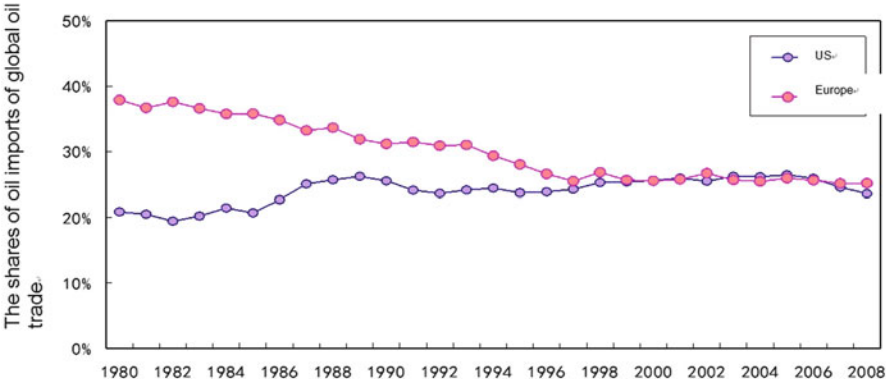

Fig. 5.10 Share of oil imports in the global oil trade of the United States and Europe, 1980–2008. *Note*: The figures for Europe before 1993 do not include those for central Europe (*Data source*: BP 2009)

5.3.3.3 Share of Oil Trade Constraint (Scenarios B and D)

China's oil imports are limited by global oil trade and the actions of other oil-importing countries: China cannot obtain as much oil as it wishes. With the increase in China's oil imports, its share in the global oil trade will be higher. To maintain a high share in the global oil trade, great costs in terms of energy security and comprehensive national strength are required.

The share of oil trade (SOT) of the United States and Europe since 1980 is presented in Fig. 5.10. The SOT of the United States has remained at 20–25 %; though the SOT of Europe has undergone reduction in recent years, it has also been around 25 %. Considering that these two strong regions can maintain just 20–25 % of the SOT, it will be quite difficult for China to attain the same level. However, in Scenario A, the SOT of China reaches 18 %.

If we set the SOT of 15 % as the energy security constraint (Scenario B), China's oil imports will be 493 Mt (OID 71 %) and its domestic oil production 200 Mt, which will be sufficient to meet the oil demand in Total Consumption Control Scenario B. However, there will be a 7-Mt oil gap in Total Consumption Control Scenario A and 92-Mt oil gap in the Linear Extrapolation Scenario.

If we set the SOT of 12 % as the energy security constraint (Scenario D), China's oil imports will be 394 Mt (OID 71 %): there will be a 6-Mt oil gap in Total Consumption Control Scenario B, a 106-Mt oil gap in Total Consumption Control Scenario A, and a 191-Mt oil gap in the Linear Extrapolation Scenario.

5.3.3.4 OID Constraint (Scenarios C, E, and F)

The rise of OID means that the total cost of importing oil will increase, and the impact of disruption in the oil supply and fluctuations in the international oil price on economic development will be greater. In domestic discussions about energy security, OID is a commonly used index. However, there are drawbacks in using only OID to evaluate energy security risks. To take a positive example, after 1980 the OID of the United States displayed a continuous increase, but in 2005 it reached a peak of 65–66 %. This is the main basis for some domestic experts advocating that China should maintain the OID below 65 % or 70 %. Another negative example is that of Japan, whose OID has been close to 100 % because it is almost totally reliant on imported oil supplies.

Considering that China will be similar to the United States in its future oil consumption and imports, there is some sense in using the OID to assess energy security constraints. If we set the OID of 70 % as the energy security constraint, China's oil imports will be 467 Mt (SOT 14 %) and domestic oil production 200 Mt, which is sufficient to meet the oil demand under Total Consumption Control Scenario B. However, there will be a 33-Mt oil gap under Total Consumption Control Scenario A and a 118-Mt oil gap in the Linear Extrapolation Scenario.

If we set the OID of 65 % as the energy security constraint, China's oil imports will be 371 Mt (SOT 11 %), and there will be a 29-Mt oil gap under Total Consumption Control Scenario B, a 129-Mt oil gap under Total Consumption Control Scenario A, and a 214-Mt oil gap under the Linear Extrapolation Scenario.

If we set the OID of 60 % as the energy security constraint, China's oil imports will be 300 Mt (SOT 9 %): there will be a 100-Mt oil gap under Total Consumption Control Scenario B, a 200-Mt oil gap under Total Consumption Control Scenario A, and a 285-Mt oil gap under the Linear Extrapolation Scenario.

The above scenario analysis results show that China's oil supply and oil gap are very sensitive to energy security constraints. This means that China needs to choose its energy security strategy with great care, and this will of course be closely related to the future situation for oil demand.

Under the Linear Extrapolation Scenario, the SOT and OID are up to 18 and 75 %, respectively, and the energy security risk is high. If we take the SOT of 15 % and OID of 70 % as the energy security constraints, the oil gap will amount to 100 Mt, and there still is hope to close the gap by means of large-scale development of oil alternatives. According to the estimation made by CAE (2011a), Chinese alternatives to oil in 2030 are expected to amount to 100 Mt. Under stricter energy security constraints, replacing oil could amount to as much as 200–300 Mt, which would be difficult to achieve.

Under Total Consumption Control Scenario A, only 7–30 Mt of oil needs to be replaced (mainly alternative fuels for vehicles); this can satisfy the SOT of 15 % and OID of 70 %. If we can make a further increase to 100 Mt of alternative oil, we still can achieve 12 % SOT and 65 % OID. However, it would be difficult to satisfy OID of 60 %, because the oil-replacement amount would be 200 Mt.

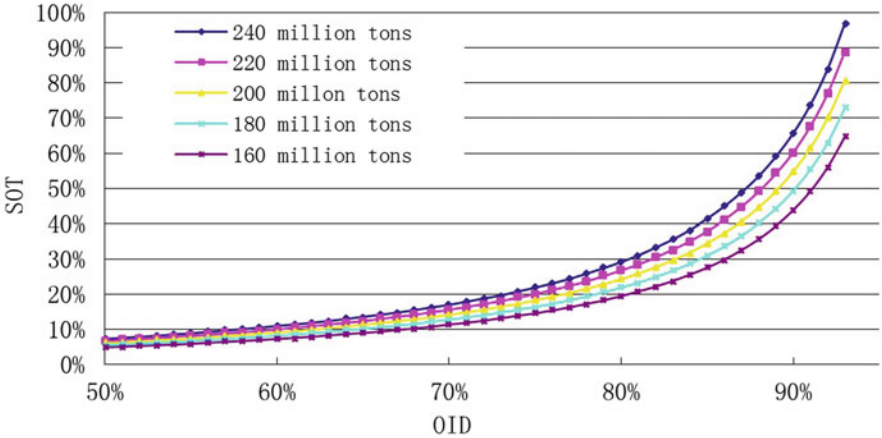

Fig. 5.11 Sensitivity-analysis curves among SOT, OID, and domestic crude oil production (for 2030)

Under Total Consumption Control Scenario B, only 6–29 Mt of oil needs to be replaced (mainly alternative fuels for vehicles), which can satisfy the SOT of 12 % and OID of 65 %. However, to meet the 60 % OID, additional oil replacement of 100 Mt is required. Because under Total Consumption Control Scenario B, we have already considered the potential of transport energy saving and vehicle alternative fuels, it is difficult to provide a further 100-Mt increase using alternative fuels.

In summary, China's energy security policy must be closely combined with a policy controlling the total amount of oil consumption. Based on the above scenario, analyses of oil demand, SOT of 15 % and OID of 70 %, are the least energy security constraint that China should aim for. Having 12 % SOT and 65 % OID would make energy security much safer and could be set as the basic policy. However, it would be difficult to control OID below 60 %.

It is should be pointed out that the above analyses have considered only limited future uncertainties. For example, there may be fluctuations in the 200-Mt domestic oil production before 2030. Figure 5.11 presents sensitivity-analysis curves among SOT, OID, and domestic crude oil production. It shows that the decline in domestic crude oil production will cause the curve to move to the lower right, which means that for the same SOT condition (when the global trade volume is fixed, the SOT is proportional to oil imports), OID will be higher. For example, if the SOT were 15 %, domestic oil production would fall from 200 to 160 Mt, OID would increase from 71 to 76 %, and the energy security risk would increase. However, if domestic oil production rose from 200 to 240 Mt, OID would drop from 71 to 67 %, and the energy security risk would be reduced.

However, if domestic oil production was excessively raised before 2030, although the energy security risk during that period would be reduced, it might result in an earlier oil peak and make long-term energy security risk much greater.

Therefore, China's oil exploration and development should be mainly devoted to improving and ensuring long-term stable oil production and avoiding volatility in the production.

In addition, there is uncertainty regarding the future global oil trade and the supply and demand of oil. An increase in the global oil trade is conducive to China's oil security to a certain extent. Rather than the OID, the proportion of imported oil costs in GDP and the impact of oil disruptions and oil price shocks on GDP may be more practical indicators for measuring energy security risk. However, since the relationships among China's macroeconomic development, oil demand, international oil prices, and the dollar exchange rate are very complex, there is considerable uncertainty over international oil prices. Therefore, these issues demand greater research and discussion.

5.3.4 Conventional and GHG Emissions

A major solution to oil-related pollution lies in a gradual improvement in the emission standards of motor vehicle exhausts with respect to international standards. However, this solution is still hindered by poor oil product quality, especially the sulfur content. The International Clean Transportation Committee points out that the high sulfur content of fuel is a significant barrier in applying reduction technology to mitigate other pollutants (such as particles).

China's fuel quality is dependent on the technological configuration of already-installed refining units (Zhang 2005). At present, the proportion of domestic FCC gasoline is as high as 75 %; this is because the feedstock of most FCC gasoline is mixed with vacuum residual fractions, and therefore the olefin and sulfur content of the FCC gasoline is quite high. This is the major reason for the poor quality of Chinese gasoline. Similarly, the proportion of catalytic hydrogenation diesel is almost 50 %, and part of the high-sulfur straight-run diesel is directly used as diesel harmonic components, which results in the high sulfur content and low hexadecane content in diesel products.

Hydrotreating and hydrofinishing can remove sulfur and impurities from oil, and these are major processes in oil refineries to improve product quality. Although in recent years China's hydrotreating and hydrofinishing capacity has continued to improve, the installation rate is still clearly lower than in developed regions. There are no technological difficulties here, but the high investment costs and inadequate market supervision in addition to other reasons deter some refineries from installing hydrotreating processing equipment. Another factor that threatens to deteriorate fuel quality is the high sulfur content in imported crude oil and the rising proportion of heavy oil; this is a common problem in world oil markets (IEA 2008; OPEC 2009). This issue will pose new barriers in improving the fuel quality of China's refineries.

In terms of reducing GHG emissions, a major potential lies downstream in the oil-supply chain, namely, traffic energy saving. However, there is also some potential in upstream areas, including oil fields and refineries. For example, in the atmospheric distillation at oil refineries, fluidized catalytic cracking and hydrocracking devices are the main source of CO_2 emissions. Fluidized catalytic cracking is in general more CO_2 intensive than hydrocracking; therefore, more hydrocracking will increase flexibility in the diesel-to-gasoline ratio and also be beneficial in reducing CO_2 emissions. In addition, carbon capture, utilization, and sequestration in oil refining are urgent issues that need to be studied.

Overall, however, to increase transport of liquid fuel production and improve fuel quality, additional technical processes need to be added to oil refineries, thereby driving up costs and energy consumption by oil refining. To lessen GHG emissions and other pollution resulting from oil consumption, substantial investment is required in addition to promoting end-use energy saving and developing oil alternatives.

5.4 Conclusions and Suggestions

Although this chapter has analyzed and discussed the whole oil-supply chain and the development of the entire transport sector, its starting point is examining petroleum-derived automotive fuels. Therefore, in this section, the focus will be on presenting proposals and insights relating to the future development of petroleum-derived automotive fuels.

5.4.1 Main Conclusions

5.4.1.1 Road Vehicles Account for the Greatest Oil Consumption

In 2009, China's road transportation (excluding motorcycles) consumed 97 % of the total gasoline, 62 % of diesel, and 5 % of LPG; this amounts to 48 % of the total consumption of petroleum products and 37 % of the total oil consumption. From 2000 to 2009, increased oil consumption by road transport accounted for 47 % of China's total increased oil consumption and was thus the main propelling force behind the growth in oil demand.

Both previous studies and the analysis in this chapter indicate that road vehicles will continue to be the main force behind future growth in oil demand. From a linear extrapolation of historical trends, oil consumption by road vehicles in 2009–2030 will account for 45 % of the total increased oil consumption; in 2030, oil consumption by road vehicles will amount to 41 % of the total oil consumption. Under Total Consumption Control Scenario A, which considers both the macroeconomic situation and oil-saving by nontransport sectors, oil consumption by road vehicles will account for up to 81 % of the total increased oil consumption, and in 2030 oil consumption by road vehicles will amount to 57 % of the total oil consumption.

5.4.1.2 Domestic Crude Oil Production Will Stabilize at Around 180–200 Mt

China's oil reserves and production have entered a stable growth stage. The country is generally not rich in terms of its oil resources, but because its reserves have huge growth potential, crude oil production up to 2050 is expected to stabilize at around 180–200 Mt. Already-proven reserves of crude oil may peak in 2020; however, considering additional reserves, technological development in exploration and extraction techniques, and unconventional resources, China's oil peak may be significantly delayed. However, all the above forecasts are based on China adopting a sustainable, stable crude oil-production strategy—as opposed to raising oil output in the near future and running the risk of future crude oil production volatility and depletion.

5.4.1.3 Oil Import Must Reflect Energy Security Constraints

Because domestic oil production is likely to remain stable, increased oil consumption will be met mainly through oil imports, which will in turn lead to increasing energy security risks. From a comprehensive consideration of the domestic oil production, the SOT available to China, and OID, an import level of 400–500 Mt would ensure energy security to a certain extent. This entails that China should avoid the high oil-consuming development path pursued by developed countries; China should greatly promote oil saving and enhance the development of alternative fuels to solve the short supply of petroleum-derived automotive fuels.

5.4.1.4 Optimizing Technical Configuration in Oil Refining

Faced with a series of serious problems, such as an imbalanced diesel-to-gasoline ratio and poor fuel quality, the overall technological configuration of China's refining industry requires urgent optimization urgently. The goals should be as follows. (1) Enhancing feedstock adaptability: with the rapidly rising proportion of oil imports, the refinery feedstock will be heavier and have a higher sulfur content. In addition, the refining scale of unconventional oil resources will also gradually increase. (2) Increasing clean transport fuel output and enhancing flexibility in the diesel-to-gasoline ratio: since oil will be increasingly used in transport, particularly road transport, newly built refineries should be technically configured to increase their output of gasoline, diesel, and kerosene. However, there may be large fluctuations in the future demand-side diesel-to-gasoline ratio, so the technical configuration of refineries must ensure great flexibility in this ratio. (3) Improving fuel quality: the key to improving fuel quality is to reduce the sulfur content so as to achieve adaptability in meeting constantly improving fuel quality standards. (4) Reducing energy losses and GHG emissions: the focus here is to reduce oil consumption per unit of output, and reducing GHG emissions demands urgent study.

5.4.2 Policy Suggestions

5.4.2.1 Increase Upstream Investment to Ensure Supplies of Vehicle Oil

Transportation energy will remain dominated by oil in the long term and such issues as energy security and control of conventional pollutions. Therefore, China should maintain long-term stable investment in crude oil exploration and exploitation, crude oil refining, and other related areas to promote technological progress. The priorities should include the following: (1) continuously promoting the exploration and exploitation of conventional and unconventional oil resources to ensure long-term stable oil supply and build strategic oil reserves; (2) optimizing refinery technical configuration (e.g., increasing the output ratio of transport fuels, such as gasoline and diesel, and reducing their sulfur content, improving the installation of hydrogenation processing and hydrotreating equipment, and enhancing flexibility in the diesel-to-gasoline ratio) to adapt to the ever-growing demand for clean transportation liquid fuel; and (3) improving carbon capture, utilization, and sequestration to handle the increasing pressure for reducing GHG emissions.

5.4.2.2 Control Total Oil Consumption and Build a National Energy Safety System

China needs to be fully aware of the complexity of energy security issues and the huge investment needed to resolve them. On the one hand, it has been proposed that a timely restriction on total oil consumption, such as upper limits of SOT of 15 % and OID of 65 %, should be carried out to restrict that consumption to the range of 600–700 Mt, thereby avoiding uncontrollable energy security risks produced by huge oil imports. On the other hand, facing the inevitable boom in oil imports in the short and medium term, China needs to do more than diversify its import channels. The country needs to implement a more proactive strategy and establish state strategic petroleum reserves. It should also resort to more unconventional measures, such as making efforts in energy security-related technology, the economy, military affairs, politics, and diplomatic relations, to further improve its energy security system and enhance its presence with respect to international oil prices and international oil resources.

5.4.2.3 Promote Oil Saving, Especially for Road Transport

To contain the growth of total oil consumption, China has to promote oil conservation at every part of the oil-supply chain and in every oil-related sector. First, oil saving should be enhanced in nontransport sectors by replacing oil with alternatives, such as coal, gas, electricity, or renewable sources. Second, it is necessary to improve oil saving in the transport sector through transport-demand management, transport-structure optimization, and improving transport energy efficiency. Since the main end use of oil is in automotive transport and because of the magnification effect in end-use oil saving, cars should be the priority in oil saving and also for reducing GHG emissions and other pollution. Fortunately, there is still significant potential for vehicle energy saving. Therefore, China should hasten the promulgation of stricter fuel economy standards and also the introduction of CO_2-mitigation standards.

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