ASIA PACIFIC ENERGY RESEARCH CENTRE

ENERGY IN CHINA: TRANSPORTATION, ELECTRIC POWER AND FUEL MARKETS

2004

About the cover:

The economy of China, recently the most dynamic in the Asia Pacific Economic Cooperation, is represented by a stylised *go* board in which the number and mix of cars, trucks, ships, trains and planes determine oil product demand for transport, while the capacity and mix of coal-fired, gas-fired, nuclear, wind and hydro powerplants affect coal and gas demand for generation of electricity.

Published by

Asia Pacific Energy Research Centre
Institute of Energy Economics, Japan
Inui Bldg.-Kachidoki 16F, 1-13-1 Kachidoki
Chuo-ku, Tokyo 104-0054 Japan
Tel: (813) 5144-8551
Fax: (813) 5144-8555
Email: apercadmin@aperc.ieej.or.jp (administration)

APEC#
ISBN 4-931482-26-0

Printed in Japan

FOREWORD

China has experienced enormous growth in its energy markets over the last two decades, fuelled by sustained growth in its economy. As rapidly expanding transportation and power production in China place increasing demands on markets for oil, gas and coal, the effects may well be felt elsewhere in the APEC region. APERC has undertaken this study to afford policy-makers a better understanding of how transport and power sector trends in China may affect fuel markets and the environment, as well as measures that might be taken to moderate the impacts foreseen.

This report is published by APERC as an independent study and does not necessarily reflect the views or policies of the APEC Energy Working Group or individual member economies. But we hope that it will help inform discussion of China's growing energy role in the APEC region.

Masaharu Fujitomi
President
Asia Pacific Energy Research Centre

ACKNOWLEDGEMENTS

We would like to thank all of those who contributed to this study, which could not have been successfully completed without the hard work and inspiration of many individuals. Kind assistance was also received from APERC administrative staff in the report's publication.

Valuable advice and insights were received from participants in APERC workshops, including Aloulou Fawzi of the Energy Information Administration (United States), Ken Koyama of the Institute of Energy Economics, Japan, Jean Ku of the National Renewable Energy Laboratory (United States), Gordon Kwan of HSBC (Hong Kong, China), Youcai Liang of the State Information Center (China), Scott Roberts of Cambridge Energy Research Associates, Karen Schneider of the Australian Bureau of Agricultural and Resource Economics, Jonathan Sinton of Lawrence Berkeley National Laboratory (United States), Aling Zhang of Tsinghua University, Yuzhuo Zhang of the Shenhua Group (China), and Qinyong Zhou of the State Grid Corporation of China .

We would also like to thank members of the APEC Energy Working Group (EWG), APEC Expert Group on Energy Data and Analysis (EGEDA), and APERC Advisory Board, along with numerous government officials, for their stimulating comments and current information.

APERC CONTRIBUTORS

PROJECT LEADER:

Yanjia Wang (China)

ASSISTANT PROJECT LEADER:

Jeffrey Skeer (United States)

PROJECT PARTICIPANTS:

Ahmad Bin Haji Mohamad (Brunei Darussalam)

Naoko Doi (Japan)

Jeong-Hwan Kim (Korea)

Martin Bonou (Papua New Guinea)

Desiderio Añora Fuerte, Jr (Philippines)

Chang-Horng Huang (Chinese Taipei)

Chung-Yang Lin (Chinese Taipei)

Vichien Tantiwisarn (Thailand)

ADMINISTRATIVE SUPPORT

Sutemi Arikawa, Shohei Okano, Sachi Goto, Mizuho Fueta and Chie Koshino.

CONTENTS

List of Figures

List of Tables

List of Abbreviations

APEC	Asia-Pacific Economic Cooperation
APERC	Asia Pacific Energy Research Centre
BAU	business as usual
Bcm	billion cubic metres
Bp-km	billion passenger-kilometres
Bt	billion tonnes (one thousand Mt)
Bt-km	billion tonne-kilometres (one thousand Mt-km)
Btu	British thermal unit
CO_2	carbon dioxide
EIA	Energy Information Administration (USA)
ERI	Energy Research Institute (China)
FGD	flue gas desulphurisation
g	gramme
GDP	gross domestic product
GW	gigawatt (one billion watts or one thousand MW)
IEA	International Energy Agency
IEEJ	Institute of Energy Economics, Japan
ITROD	incremental transport-related oil demand
kg	kilogrammes (one thousand grammes)
km	kilometres
ktoe	kilotonnes oil equivalent (one thousand toe)
kW	kilowatt (one thousand watts)
kWh	kilowatt-hour (one thousand watt-hours)
LBNL	Lawrence Berkeley National Laboratory (USA)
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MBpd	million barrels per day
MBtu	million British thermal units
Mt	million tonnes
Mt-km	million tonne-kilometres
Mtoe	million tonnes of oil equivalent
MW	megawatt (one thousand kW)
NBS	National Bureau of Statistics (China)
NDRC	National Development and Reform Commission (China)
NOx	nitrogen oxides
p-km	passenger-kilometre (one person moved one km)
PSE	pollutant standard equivalent
Quad	quadrillion Btu (one billion MBtu)
SETC	State Economic and Trade Commission (China)
SO_2	sulphur dioxide
SSTC	State Science and Technology Commission (China)
tce	tonne coal equivalent
Tcf	trillion cubic feet
t-km	tonne-kilometre (one tonne moved one km)
toe	tonne oil equivalent (39.68 MBtu)
TWh	terawatt hour (one trillion watt-hours or one billion kWh)

EXECUTIVE SUMMARY

GENERAL ENERGY TRENDS IN CHINA

China's energy use has grown more than 5 percent per year on average since 1980. Coal provides seven-tenths of the economy's energy, mostly for electricity generation, and oil provides a quarter, mostly for transport. China is self-sufficient in coal but must import 30 percent of its oil.

Various studies project that China's final energy demand will grow between 2.2 and 2.7 percent per annum through 2020 or 2030. But the same studies project much faster growth of 3.0 to 4.9 percent per annum in oil demand and 5.5 to 11.6 percent per annum in gas demand. Much of the oil demand growth will be driven by growth in transport, projected at 4.0 to 5.3 percent per annum.

TRANSPORTATION AND OIL IMPORTS IN CHINA

China's transportation sector has been growing rapidly, along with its energy consumption:

- From 1980 through 2002, highways doubled in length, freight traffic quadrupled, passenger traffic grew six-fold and civilian air traffic grew eight-fold. Passenger traffic grew four-fold on railways, ten-fold on highways, and thirty-fold in aviation. Freight traffic, tripling by rail, grew five-fold by waterway and nine-fold by highway. Overall transport volume grew 72 percent as fast as China's gross domestic product.
- From 1990 to 2002, with rising incomes, motor vehicle production grew six-fold, private vehicle ownership twelve-fold, and passenger car production thirty-fold.
- From 1990 to 2000, energy consumption for transport grew 80 percent, energy consumption for highway transport grew 157 percent, and the highway share of total energy use for transport grew from 48 percent to 68 percent. The energy intensity of transport, in tonnes oil equivalent per million tonne-kilometres, rose 6 percent for transportation as a whole even though it fell 36 percent on railways and 52 percent on waterways, mainly because it rose 37 percent on highways.

A range of projections may be made for growth in China's transport energy use from 2002 to 2020, assuming that the economy grows 7 percent per annum as anticipated by government planners, that oil in 2020 costs between $17 and $35 per barrel as indicated in recent projections, and that the elasticity of oil supply with respect to price is somewhere between 1 and 3:

- *Medium Transport Growth:* Transport volume grows 70 percent as fast as GDP, and the energy intensity of transport rises half as fast as it did from 1990 to 2000. Total demand for transport fuels grows 162 billion tonnes. Gasoline's share of oil product demand rises to 29 percent. About 60 percent of oil is imported, and China's yearly oil import bill grows by US$23 billion to $48 billion. The impact on world oil prices in 2020 might range from US$0.19 to $1.25 per barrel.
- *Low Transport Growth:* Transport volume grows half as fast as GDP, and the energy intensity of transport stays at 2000 levels. Transport fuel demand grows 93 Bt. Gasoline's share of oil product demand rises to 26 percent. Some 52 percent of oil is imported, and China's yearly oil import bill grows by $13 billion to $27 billion. The impact on world oil prices in 2020 might range from $0.10 to $0.73 per barrel.
- *High Transport Growth:* Transport volume grows 90 percent as fast as GDP, as it has during some historical periods, and the energy intensity of transport rises just as fast as it did from 1990 to 2000. Demand for transport fuels grows 255 Bt. Gasoline's share of oil product demand rises to 32 percent. Some 68 percent of oil is imported, and China's yearly oil import bill grows by $37 billion to $75 billion. The impact on world oil prices in 2020 might range from $0.31 to $1.97 per barrel.

Since fuel use in China's transport sector will rise sharply under any reasonable assumptions, there will be huge increases in China's crude oil and petroleum product imports, as well as huge needs for investment in new petroleum refinery capacity both in China and elsewhere in APEC. In the face of growing import dependency, China is likely to boost its oil security by diversifying its sources of crude oil and oil product supply, building oil stockpiles, and limiting demand growth through policies to control road traffic in cities and improve the fuel economy of highway vehicles.

ELECTRIC POWER IN CHINA: IMPACTS ON GAS AND COAL USE

Coal is used to generate about three-quarters of China's electricity and is likely to remain the dominant fuel for electric power production in the foreseeable future. However, significant and growing amounts of electricity are being generated by natural gas, hydropower and nuclear power:

- *Hydropower* generates a sixth of China's electricity, and hydroelectric capacity could double by 2020 to 170 gigawatts, exploiting 45 percent of China's hydro potential.
- *Nuclear power* also seems likely to assume an important role, as plans are in place for construction of 25 gigawatts of new nuclear generating capacity by 2020.
- *Natural gas* is being promoted due to its low emissions of atmospheric pollutants and carbon dioxide, and 20 gigawatts of gas-fired capacity are planned by 2010.

At present, coal-fired power holds a clear economic advantage over gas-fired power in China:

- *With average fuel prices and capital costs,* gas-fired power is roughly two-thirds more costly than coal-fired power per kilowatt-hour. The comparison is between new coal plants with desulphurisation equipment and 36 percent generating efficiency and new combined cycle gas plants with 50 percent generating efficiency, both operating in baseload at a 76 percent capacity factor. Capital costs are amortised assuming a 10 percent discount rate and 25-year financial lifetime Gas is assumed to cost $3.85 per million Btu in accord with prices for gas delivered from the West-to-East pipeline. Coal is assumed to cost $25.30 per tonne, per recent averages.
- *But under favourable conditions for gas,* gas-fired power could undercut coal-fired power in cost by nearly a quarter. This assumes advanced technology allowing higher gas-plant efficiency of 58 percent, as well as lower gas costs of $3 per million Btu and higher coal costs of $45 per tonne in plants located far from coal mining areas.
- *Sensitivity analysis* indicates that the cost comparison between coal- and gas-fired power would be little changed by different assumptions about discount rates or plant lifetimes, but could be changed significantly by a stronger Chinese currency.

The economic comparison between coal- and gas-fired power in China could change with the introduction of carbon dioxide charges and carbon sequestration technology in the longer term:

- *With a charge of $20 per tonne of carbon dioxide under average cost conditions,* gas-fired power would be only slightly more expensive than coal-fired power at current exchange rates and could be cheaper than coal-fired power if the yuan appreciates.
- *Carbon sequestration technology* could be economical with a carbon dioxide charge of $22 per tonne or more under average fuel and capital cost conditions. Employing sequestration, coal- and gas-fired power would be similar in cost if a carbon dioxide charge of up to $35 per tonne were imposed, but gas-fired power would enjoy a clear cost advantage if the carbon dioxide charge were higher. This assumes sequestration of 80 percent of carbon from coal-fired plants at a cost of $840 per kilowatt and 85 percent of carbon from gas plants for $380 per kilowatt.

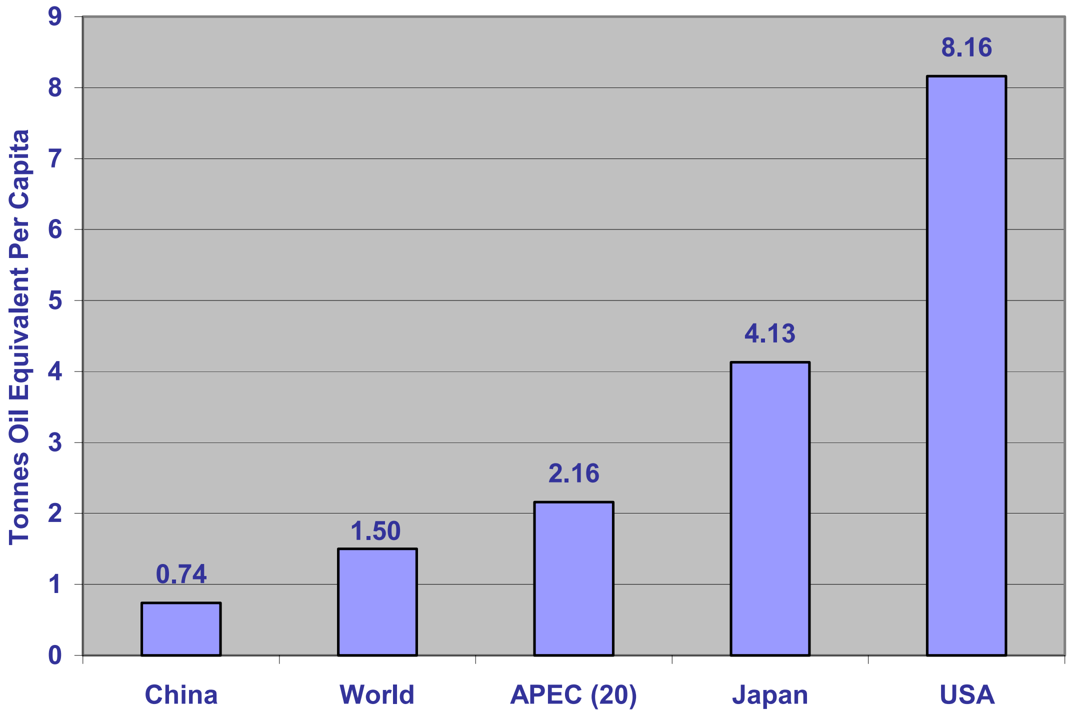
By 2020, annual pollutant emissions from China's power production may reach 5.2 to 8.0 Bt of sulphur dioxide, 2.6 to 3.7 Bt of nitrogen oxides, and 1.4 to 2.5 trillion tonnes of carbon dioxide. With effective control technologies, however, atmospheric emissions could be substantially lower.

INTRODUCTION

BACKGROUND

In the last twenty years, China's economic output has quadrupled and its energy consumption has doubled. China has thus become the second-largest energy producer and consumer among all the economies of the Asia Pacific Economic Cooperation region and the world, surpassed only by the United States. Yet while China consumes a tenth of the world's total energy, its energy consumption per capita is only about half the world average, a third of the APEC average, a fifth of Japan's, and just one-eleventh as high as in the United States. Consequently, it stands to reason that as China's growth continues and China's level of energy consumption per person approaches levels elsewhere in APEC, the incremental effect on world energy markets will be substantial.

Figure 1 Primary Energy Consumption per Capita in 2000 (Tonnes Oil Equivalent)



Source: IEEJ (2003). APEC data shown exclude Papua New Guinea.

A key concern of policymakers in energy-importing APEC economies is the potential impact of China's growing oil use on world crude oil and petroleum product markets. In the last ten years, China's oil consumption has doubled, and China is poised to replace Japan as the second-largest oil consuming economy after the United States. Continued oil demand growth in China and elsewhere could thus keep world oil prices at high levels even if oil producers do not aim to limit their output.

Another major concern is the potential impact of China's growing energy needs on the environment. Growing carbon emissions from oil use in the transportation sector, as well as growing use of coal for electricity production, are likely to add significantly to total world emissions. China is one of the few economies in the world in which coal is the dominant fuel, and that makes its carbon intensity per unit of energy production much higher than in most other economies.

Analysis can help to shed light on the best available approaches to address these concerns. How fast is transportation demand in China likely to grow in coming years, and along with it demand for oil? How would that affect world oil prices, and what policies might slow the growth? How fast will demand for electricity be growing, and how much electricity will be supplied by coal? How might carbon taxes and sequestration technology limit the environmental consequences?

STUDY SCOPE AND OBJECTIVES

This study aims to give policymakers a clearer picture of where China's energy use is headed, what that implies for other APEC members. It also suggests how growth in China's energy use and associated environmental impacts might be limited without unduly constraining economic growth in China or in the APEC neighbours with which it trades. Finally, through better understanding of the energy situation, energy policies and energy institutions in China, the study hopes to promote cooperation on energy issues in the APEC region and thereby to enhance regional energy security.

A specific objective of the study is to examine the links between transportation needs in China, demand for oil, and prices on world oil markets. How do trends in freight and passenger transport, including the mix between highways, waterways, and railways, affect the energy intensity of China's transport system and the amount of oil and petroleum products China needs to import? What policies might help to steer those trends in a more energy-efficient, less oil-dependent direction? What could be the associated benefits in terms of reduced oil bills and atmospheric pollution?

Another specific objective of the study is to look at the relationship between China's growing needs for electric power, the mix of generating plants that is built, and environmental policies. To what extent is natural gas a realistic alternative to coal for electricity generation? If more natural gas were used, to what extent might growth in carbon dioxide emissions be curtailed? At what level would carbon taxes tip the economic calculus in favour of gas-fired power? Could carbon sequestration technology preserve a key role for coal in China's power mix as concerns mount over global warming, helping to limit long-term pressures on regional gas markets?

OUTLINE OF THE REPORT

Following this introduction, the report sketches China's energy picture today and reviews trends affecting China's energy future. In a chapter on energy in China today, the report describes how energy use in China is driven by economic growth targets and briefly outlines the current role of oil, coal and natural gas in China's energy mix. In the succeeding chapter on trends and uncertainties in China's energy future, the report describes what recent studies have projected for China's energy demand and fuel requirements over the next two to three decades.

The following three chapters focus on China's transportation sector. The first of these offers a detailed look at trends in freight and passenger transport in China and how they affect energy demand. The second examines a range of scenarios for growth in transport demand, as a function of growth in China's economy and the energy intensity of transport, to assess what China's burgeoning transport sector may imply for its use and imports of crude oil and petroleum products through 2020. The third transportation chapter examines how China's growing oil imports might affect APEC oil security, in terms of China's fuel costs and world oil prices, and reviews some policies and measures that might enhance oil security by curbing growth in energy use for transport.

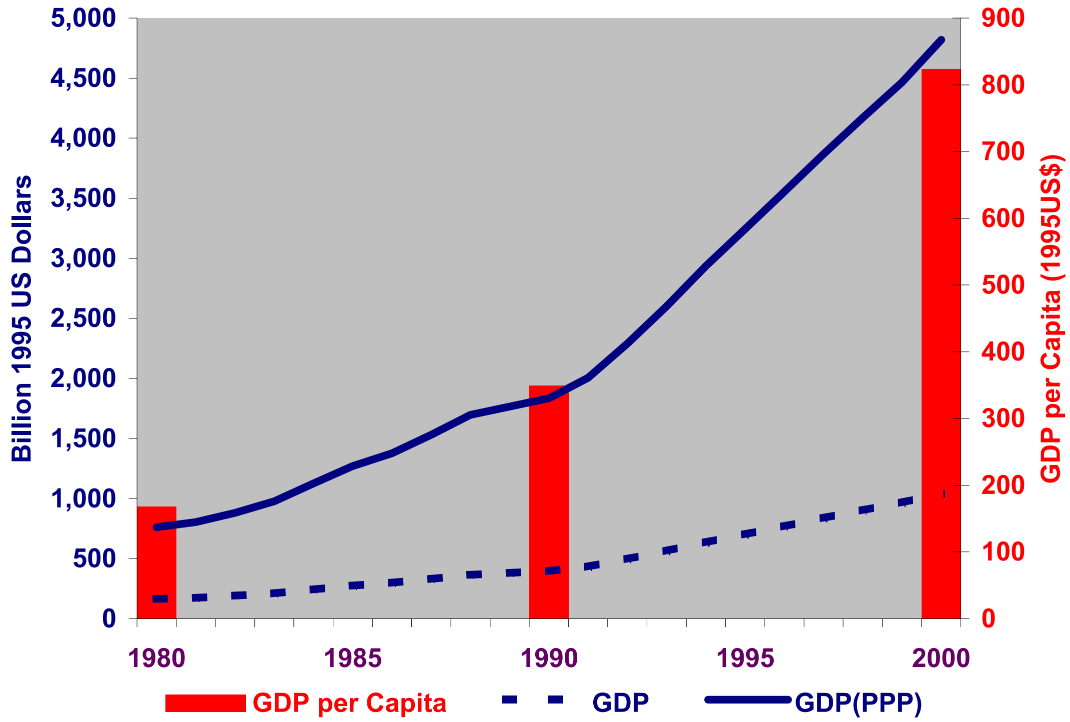
The final three chapters of this report focus on China's electric power sector. The first of these looks at trends in the power sector, briefly reviewing the prospective roles of coal, gas, hydropower, and nuclear power in China's generating mix through 2020. The second spotlights the economic contest between coal-fired power and gas-fired power, with coal favoured by low capital and fuel costs and gas favoured by its low environmental impacts. The capital, fuel and environmental cost components of fossil-fuelled generating options are all developed in detail, so that the implications of possible future carbon taxes and sequestration technology can be understood. The final chapter then examines how China's electricity generating mix may affect fuel markets and the environment.

ENERGY IN CHINA TODAY: TARGET-DRIVEN GROWTH

ACHIEVEMENTS OF DEVELOPMENT

China's economy has been developing at a remarkable pace. From 1980 to 2000, the annual rate of growth in its GDP averaged 9.7 percent, which was 4 percentage points higher than the world average during the same period. Meanwhile, real GDP per capita increased nearly five-fold from US$169 in 1980 to US$824 in 2000 (at 1995 prices). Figure 2 shows the upward trends.

Figure 2 Growth in China's Gross Domestic Product and GDP per Capita, 1980-2000



Sourrce: APEC Energy Working Group (2002)

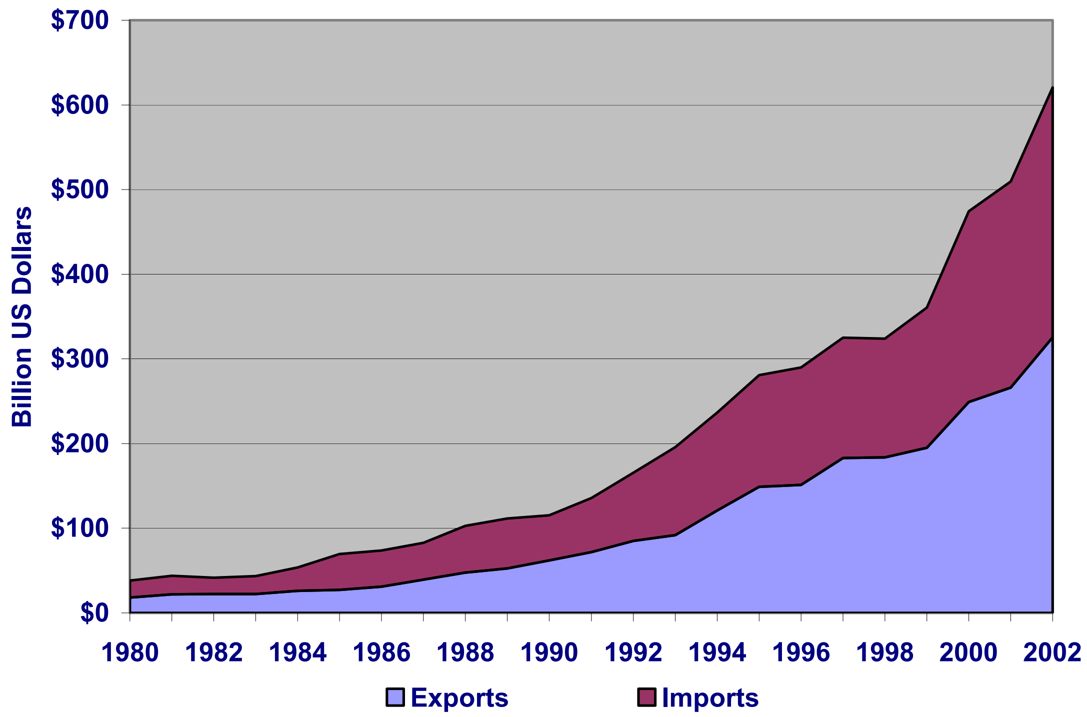
People living in China have felt the development in their daily lives: more money in their pockets, more traffic on the roads, tall buildings sprouting like mushrooms in cities and abundant goods in markets. One measure of their improved well-being is the Engel coefficient. A coefficient value of 0.6 or above corresponds to poverty, while a value of 0.5 to 0.6 indicates adequate food and clothing. If the coefficient is between 0.4 and 0.5, it indicates people are well-off, while a value of 0.3 to 0.4 shows people have become wealthy and a value below 0.3 shows they are very rich. The following may be observed about economic well-being for the period from 1980 through 2002:

- For urban households, as disposable income per capita grew from 480 yuan to 7,700 yuan, the Engel coefficient fell from 0.569 to 0.377. This indicates that the average urban household went from an adequate living standard to being wealthy.
- For rural households, as disposable income per capita increased from 190 yuan to 2,480 yuan, the Engel coefficient fell from 0.618 to 0.462. This indicates that the average rural household went from a condition of poverty to being well-off. [1]

[1] China Statistical Yearbook (2003).

Outside of China, people have felt the development through greater trade. From 1980 to 2002, the total value of China's imports and exports grew fifteen-fold as shown in Figure 3.

Figure 3 The Growing Value of China's Import and Export Trade, 1980-2002



Source: China Statistical Yearbook 2003

CHINA'S TARGET-DRIVEN ECONOMY

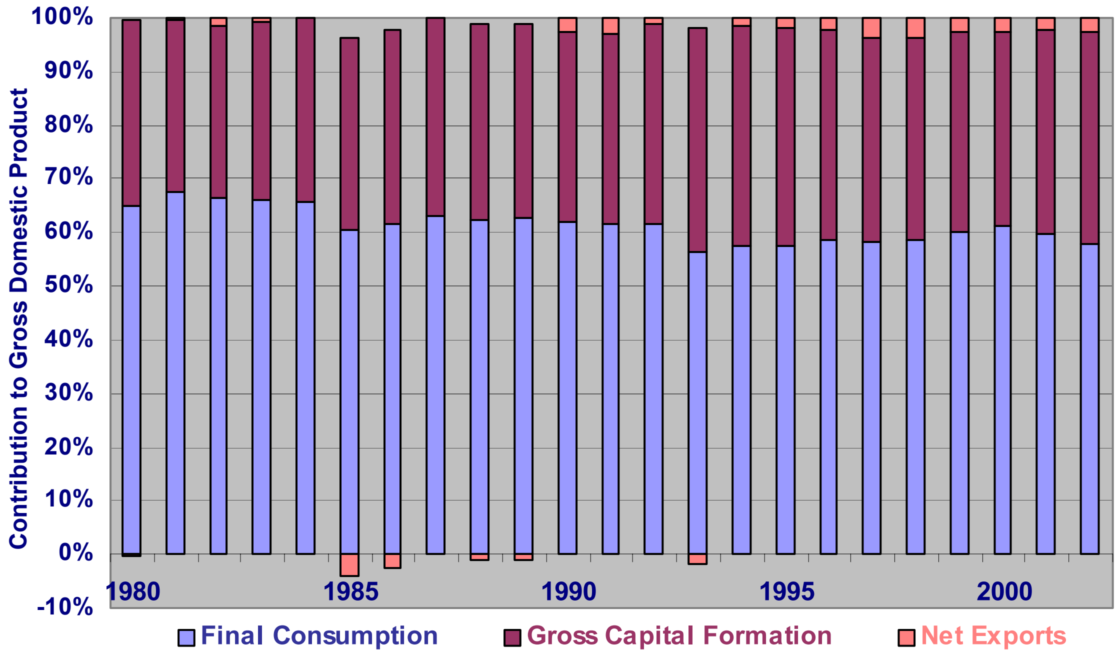
Development targets drive China's economy. The Central Commission of the Communist Party of China makes long-term strategic development plans to guide economic development. In the 1980s, a "fourfold" target was set that the GDP in 2000 would be four times that in 1980. In 2002, another "fourfold" target was set that the GDP in 2020 would be four times that in 2000. Fourfold growth over two decades implies average growth of roughly 7 percent per annum.

National five-year development plans are made in order to achieve the strategic planning goals. The central government assigns an initial development target to each major industrial sector and each provincial government. Each industrial sector and provincial government then makes its own development plan, committing itself to achieve the target it has been assigned. The national development target for the five-year plan is then obtained by summing the targets to which the various sectors and provincial governments have committed. Normally, the national development target is greater than the sum of the initial targets assigned. More-developed provinces want to raise their development targets because they think they have the capacity to develop quickly. Less-developed provinces want to develop as fast as possible to catch up with more-developed provinces.

Provincial governments naturally rely on inputs from local governments in elaborating their development targets. Local governments seek to fund local projects such as highway construction, as well as to expand local manufacturing industry through the introduction of overseas capital. They also seek to have large projects approved by the central government located in their area, since such projects have major benefits in terms of jobs, output and tax revenue. Thus, local governments in many provinces have proposed to build nuclear power plants in their area, in contrast to the "not in my backyard" syndrome that prevails in many economies today.

Through the systematic and centralised economic planning process, China's government is able to ensure a high allocation of funds to capital projects that contribute to development goals. Consequently, capital formation has consistently comprised more than a third of China's gross domestic product over the last two decades, as shown in Figure 4. Domestic consumption, meanwhile, has contributed less than 65 percent of GDP, as compared with more than 70 percent in most other economies. Perhaps somewhat surprisingly, despite the very rapid growth in trade noted above, the contribution of net exports to GDP has so far been very modest.

Figure 4 The Contribution of Capital Formation to China's GDP, 1980-2002



Source: China Statistical Yearbook 2003

The central government has periodically announced major long-term programmes to encourage economic development and improve people's living standards. In recent years, the themes of these programmes have included Rebuilding the Northeast, Developing the West, Building the Automobile Industry, and Enlarging Investment in Infrastructure by Raising Public Bonds. The government also has more general planning goals, such as guaranteeing economic development and promoting sustainable development. Under the rubric of sustainable development, the government intends to pursue energy efficiency and conservation, clean coal and gas technology for power production, renewable energy sources, and nuclear power.

In the next fifteen years, China will invest some 500 billion yuan (US$60 billion) to speed up development of alternative energy forms. The National Development and Reform Commission has set the following targets related to electricity generation:

- Nuclear power is to reach 4 percent of total installed generating capacity in the power sector by 2020. In pursuit of this target, 28 nuclear powerplants with 32 gigawatts of capacity are planned or under construction in coastal areas with a total anticipated investment of more than 360 billion yuan (US$43 billion).
- Renewable energy, excluding large-scale hydropower, is to make up 12 percent of total generating capacity for power production by 2020, or roughly 120 gigawatts. To help achieve this target, $200 billion yuan (US$24 billion) will be invested in the development of wind power, solar power, and mini-hydro powerplants.[2]

[2] Shi, L. (2004)

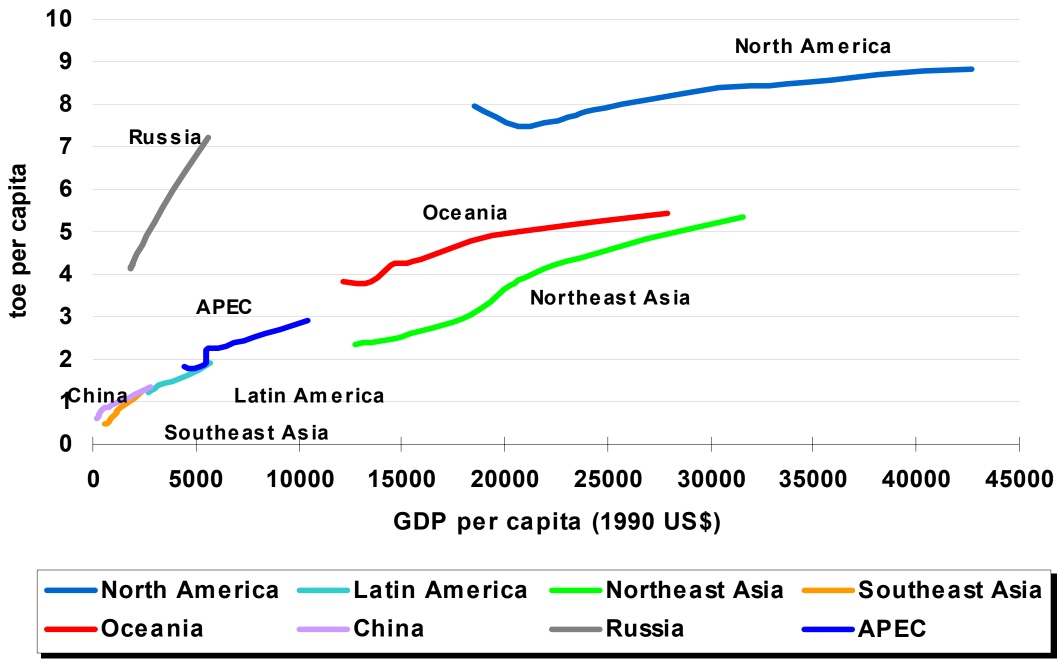
The Ministry of Communications has set the following targets for transportation, which will affect China's oil needs by making it possible for goods and people to travel more freely:

- Highways and expressways are to expand by 35,000 kilometres per year, so that the road network links more than 200 cities with half of China's population by 2020.
- Some 16,000 kilometres of new railway are to be built by 2020, so that the total length of railways in operation will reach 100,000 kilometres China-wide.[3]

GROWING PROSPERITY AND ENERGY USE

Historically, growing prosperity has meant growing energy use for economies around the globe. As shown in Figure 5, a clear relationship exists between levels of economic output per capita and energy consumption per capita in the economies of APEC. Growing energy use requires more primary energy supply such as oil, coal, gas, nuclear power and hydropower production. In addition, growing energy use requires more energy conversion facilities like oil refineries and electric power plants to provide energy in a clean and convenient form to final users.

Figure 5 Growing Prosperity and Energy Use in APEC Economic Regions



Source: APERC (2002b)

In China, as elsewhere in APEC, economic growth has brought rising energy consumption, though energy use is growing somewhat slower than GDP. China's energy use grew from 427 million tonnes oil equivalent (toe) in 1980 to 930 million toe in 1997, at an average annual rate of 4.7 percent. That was almost three times as fast as the world as a whole, in which energy use grew an average of just 1.7 percent per year during the same period. While China's energy consumption declined from 1998 to 2000 in the wake of the Asian financial crisis, it has since started growing again. In 2002, China consumed 998 million tonnes of oil equivalent, or 19.7 percent more energy than in 2001. In 2003, China's energy use grew about another 15 percent.[4]

China has a large energy industry to support economic and social development. China was the world's largest coal producer, second-largest electricity producer, second-largest oil refinery capacity owner, fourth-largest crude oil producer, and fourth-largest hydropower generator in 2002. The total value-added of China's energy sector accounted for nearly 10 percent of GDP that year.

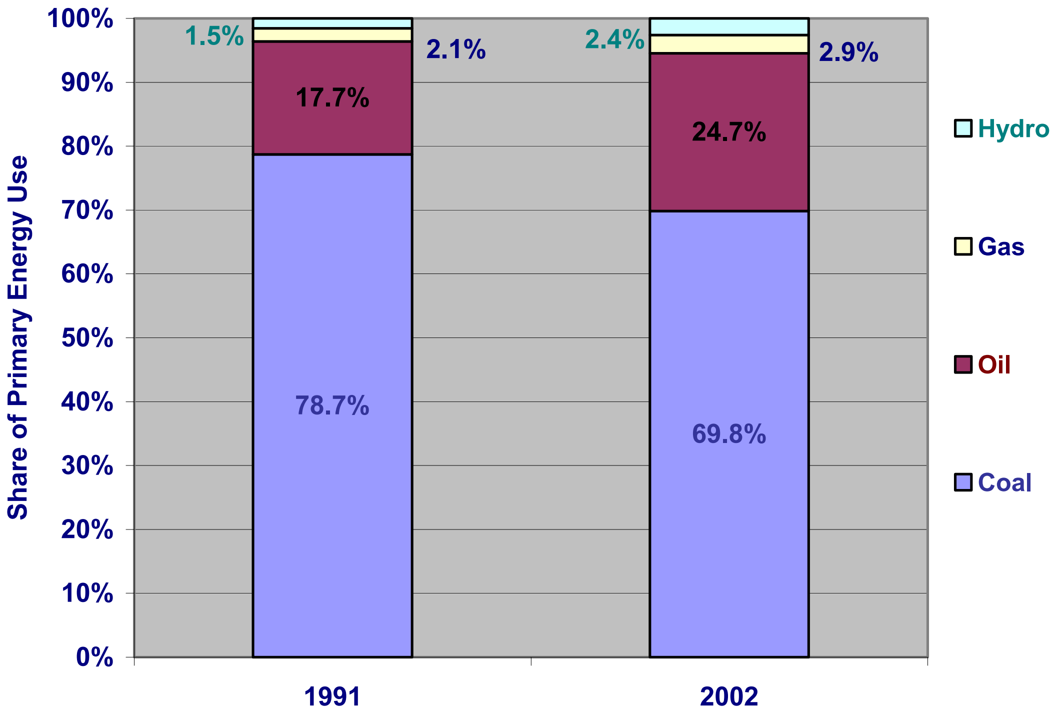
[3] Huang (2004).

[4] BP (2003).

COAL IS STILL KING IN CHINA'S ENERGY MIX

Coal is used to generate 80 percent of China's electricity, meeting 70 percent of its primary energy demand. China's coal production more than doubled from 620 million tonnes in 1980 to 1,380 million tons in 2002. Yet the role of coal has receded somewhat as the transport sector has grown, boosting the relative importance of oil in China's energy mix. As shown in Figure 6, the share of coal declined about 9 percentage points between 1991 and 2002, while the share of oil grew by 7 percentage points. Hydropower, gas and nuclear power play a small but growing part.[5]

Figure 6 China's Changing Primary Energy Mix, 1991-2002



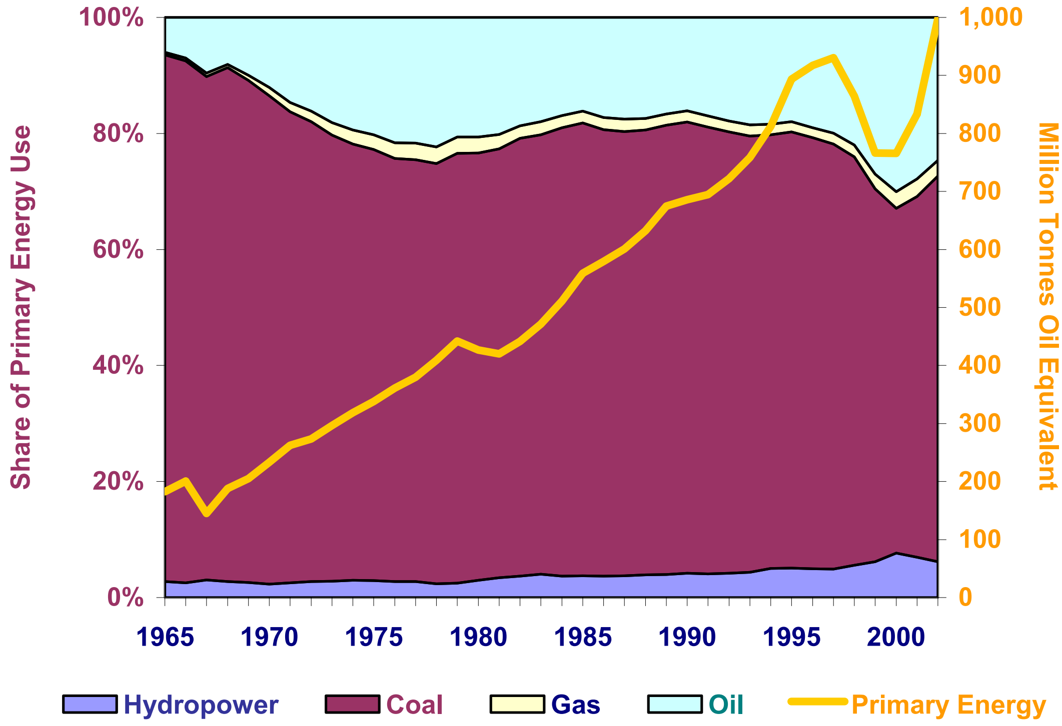
Sources: National Bureau of Statistics (2001), (2003a). State Economic and Trade Commission (2003b).
Note: Nuclear power was absent in 1991 but constituted 0.2 percent of the primary energy mix in 2002.

Coal has traditionally been viewed as vital to the long-term security of China's energy supply. In the 1980s, promotion of small-scale coal mines owned by towns and villages helped bring an end to energy shortages. When fuel oil prices rose after the oil crises of 1973 and 1979, coal was seen as the main fuel option for keeping fuel oil consumption at a reasonable level. More recently, as oil requirements for transport have continued to grow, and domestic oil output has not been able to keep pace, coal liquefaction is being considered as a way of meeting China's liquid fuel needs.

Since coal still provides about seven-tenths of China's energy supply and the economy's primary energy needs have surpassed a billion tonnes of oil equivalent, as shown in Figure 7, it is clear that large amounts of coal will continue to be used in China long into the future. Historically, at times when less electricity is needed, coal production and use has declined somewhat since coal-fired has had lower generating efficiency and greater pollutant emissions than other types of generation. But in general, reliance on coal has been heavy due to its domestic abundance and low prices. And penetration of alternative generating sources, such as hydropower, nuclear power and natural gas, is expected to be gradual, despite steady investment in such sources. The most important issue for China's power sector is therefore to consider how to use coal in a more efficient and clean way.

[5] NBS (2001) and (2003a). SETC (2003b).

Figure 7 China's Growing Primary Energy Consumption and Energy Mix, 1965-2002



Source: BP (2003)

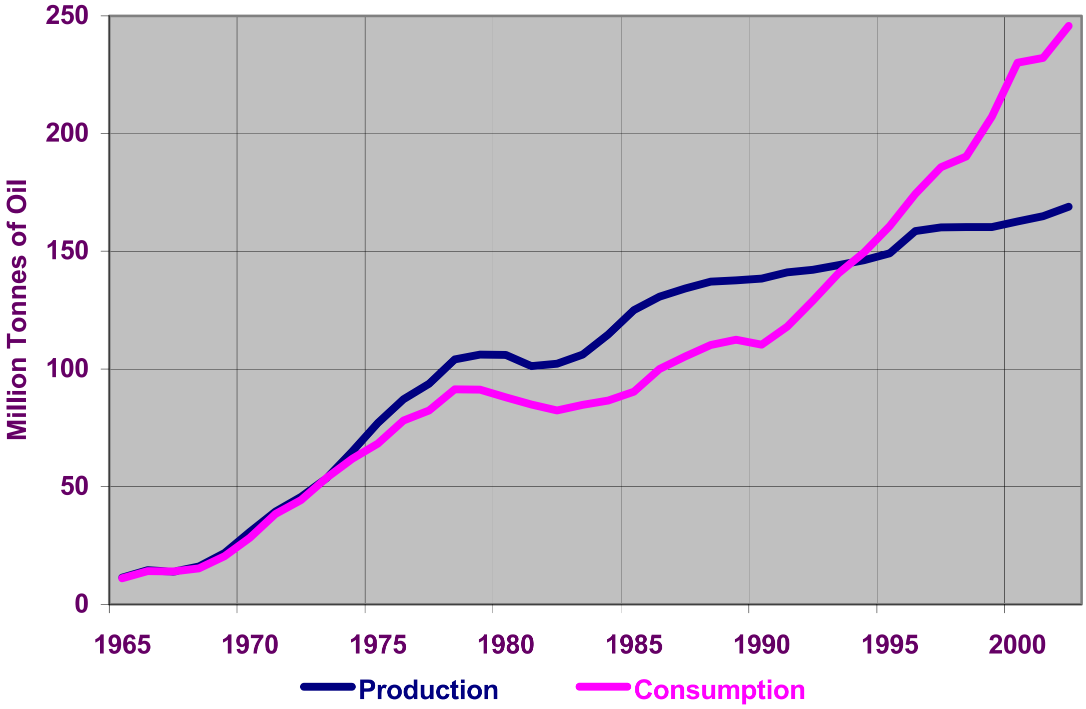
THE EMERGING ISSUE OF OIL IMPORT DEPENDENCY

During the two oil crises of the 1970s, China had more than enough domestic oil production to meet its needs. Indeed, it was a substantial exporter of oil to other economies, and oil was one of China's main commodities for earning foreign exchange. After China became a net importer of oil in the 1990s, there was little concern about oil supply security because oil prices were generally quite low, remaining below US$20 per barrel through the third quarter of 1999. Indeed, many thought that China should take advantage of cheap oil to help boost economic growth. However, a number of recent factors have focused government policy-makers on oil security as a serious issue:

- After many years of effort to enhance domestic oil production through the application of new drilling and extraction technology, policy-makers began to realise that it would be difficult to increase future oil production very much.
- Overseas oil projects by Chinese companies have not gone as well as expected.
- Growth in domestic oil consumption and imports has been faster than expected due to rapid growth in freight and passenger highway transportation.
- Alternatives to oil in the transport sector will take a long time to develop.
- Oil prices have consistently remained at high levels.

Figure 8 shows China's oil production and consumption. In the two decades form 1974 to 1993, China produced more oil than it consumed and was a net oil exporter. But since the mid-1990s, China has become a net oil importer, no longer able to produce enough oil to meet its rapidly expanding road transport needs. By 2002, China's oil import dependency exceeded 30 percent, creating a real risk for economic development and social stability if disruptions should occur in foreign oil supplies. Hence, China has started building oil stockpiles, which eventually are to meet the International Energy Agency's standard of capacity equal to 90 days of import volume.

Figure 8 Oil Production and Consumption in China, 1965-2002



Source: BP (2003)

THE BEGINNINGS OF NATURAL GAS DEVELOPMENT

As shown in the charts above, natural gas still accounts for only about 3 percent of China's primary energy demand. Gas use has been growing quite slowly, mainly because coal is far cheaper than gas as a fuel for generating electric power. Yet gas has significant advantages over coal in terms of reduced atmospheric emissions of particulates, sulphur dioxide, nitrogen oxides, and carbon dioxide. As concern increases over air quality in China's increasingly crowded cities and the contribution of carbon dioxide emissions to global warming, the position of gas should improve.

Several major developments have boosted China's natural gas supply in recent years:

- The West-to-East gas pipeline, running from Talimu in Xinjiang province through several other provinces to the coastal city of Shanghai, is to be completed in late 2004 with the capacity to transport 12 billion cubic metres of gas per year.
- The Guangdong liquefied natural gas (LNG) project is to be completed in 2005 or 2006 at a projected investment cost of some 30 billion yuan (US$3.6 billion), including receiving terminals, regasification facilities, storage facilities, 6 power-plants with 6 gigawatts of capacity, and 334 km of pipeline. A contract for 145 billion yuan (US$17.5 billion) was signed with Australia in 2003 to supply 4 billion cubic metres of gas per year for 25 years beginning in 2006.[6]

Other major gas developments are anticipated in the near future:

- A gas pipeline from Irkutsk in Russia could bring an additional 20 Bcm after 2010.
- A pipeline form Sakhalin to Shenyang could bring 10 Bcm of gas to the Northeast.
- A pipeline from Kazakhstan, Turkmenistan and Western Siberia to Xinjiang, connecting with the West-to-East Pipeline, would send 60 Bcm to Shanghai.
- LNG terminals planned for Guangdong Phase II, Fujian, and Shangdong could add a further 11.2 Bcm of natural gas import capacity to the economy.

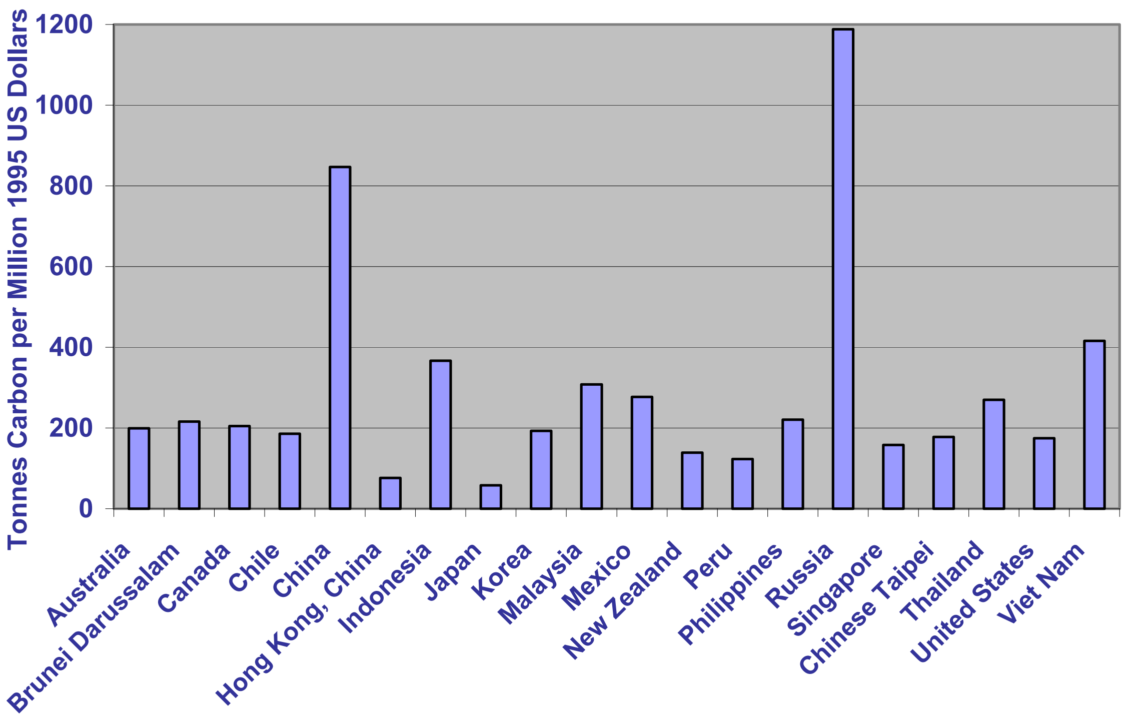
[6] Mi (2003). Qiu (2003). Chen, H. (2003).

GROWING PRESSURE TO LIMIT EMISSIONS OF CARBON DIOXIDE

Because of China's heavy reliance on coal for electricity production, cooking and heating, the carbon intensity of its economy is one of the very highest in the world. Figure 9 shows the carbon intensity of China and other APEC economies in 2000, in tonnes of carbon per million 1995 US dollars of gross domestic product. As can be seen, at over 800 tonnes of carbon per million dollars of GDP, China's carbon intensity was second only to Russia's and more than four times as high as in Australia and the United States, which are also highly reliant on coal for power production.

As a developing economy, China did not assume obligations under the Kyoto Protocol, which may not in any case go into effect. However, China intends to adopt measures that would help to limit its greenhouse gas emissions to some degree in the future. As already noted, fuel switching and efficiency improvement can reduce carbon dioxide emissions substantially. China plans to develop more nuclear power and use more natural gas to slow down the emission growth rate. China's government has been involved in the Carbon Sequestration Leadership Forum and is willing to make efforts on carbon sequestration technology development and policy-making. [7]

Figure 9 Carbon Intensity of Gross Domestic Product for APEC Economies in 2000



Source: IEEJ (2003)

SUMMARY OBSERVATIONS

China's economy has been growing rapidly over the last two decades, and energy consumption has grown along with it, though at only about half the pace. In the transportation sector, rapidly growing oil use has made China a major oil importer, with a growing impact on world oil markets. In the electricity sector, coal remains the dominant fuel, but environmental concerns have created important openings for cleaner power sources such as gas, hydro, nuclear and wind. The following chapters consider the extent to which these recent trends are likely to continue, the likely impacts on world fuel markets and the environment, and policy options for moderating those impacts.

[7] Yang (2003).

CHINA'S ENERGY FUTURE: TRENDS AND UNCERTAINTIES

INTRODUCTION

Over the past two decades, China's economy and energy consumption have been on a path of steady growth. Most projections indicate that China will continue along this path, so that China's energy use two decades hence will be much greater than it is today. But while the general trend is clear, there are still major uncertainties about how fast energy use will grow in each major sector of China's economy, and how fast demand will grow for each major fuel. The pace of growth in energy and fuel use will be determined not only by the rate of economic growth, but also by a variety of socio-economic factors such as population growth, urbanisation and the mix of products and services the economy requires. There are differing views on how these underlying factors will evolve, and hence on future energy trends.

To shed light on where China's energy future may be headed, this chapter reviews and compares several recent projections. These are drawn from studies by the Asia Pacific Energy Research Centre (APERC), the International Energy Agency (IEA), the Energy Information Administration (EIA) and Lawrence Berkeley National Laboratory (LBNL) in the United States, and Tsinghua University in China. Each of these studies focuses especially on China, and each has a somewhat different viewpoint about how and why China's energy use will evolve. The methodology of each study is described, and their projections of energy demand, electricity demand and oil demand are compared, to show how experts agree and disagree about China's energy future.

CHINA'S POSITION IN THE ASIA PACIFIC ENERGY MIX

China is APEC's largest economy in terms of population, the second-largest in terms of energy consumption, and the third-largest in terms of economic output. However, as shown in Table 1, while China's share of the APEC region's population declined only slightly between 1980 and 2000, remaining around 53 percent, its share of economic output tripled from 1.7 percent to 5.4 percent, and its share of primary energy consumption grew by half, from 13.5 percent to 19.0 percent.[8] Yet China's energy consumption was just 0.73 toe per capita in 2000, as compared with 4.14 toe in Japan, 8.17 toe in the United States, and 1.57 toe in the rest of APEC.[9] Thus, as its income levels rise and energy use per capita increases, China's share of APEC's energy use could increase as well.

Table 1 GDP, Population, Energy Use and Carbon Dioxide Emissions in APEC: Comparison of China and Other Economy Shares in 1980 and 2000

Indicator	China	Japan	USA	Other	APEC
GDP (Billion US$) 1980	164 (1.7%)	3,304 (33.8%)	4,772 (48.9%)	1,526 (15.6%)	9,766 (100%)
GDP (Billion US$) 2000	1,040 (5.4%)	5,688 (29.4%)	9,009 (46.6%)	3,589 (18.6%)	19,326 (100%)
Population (Million) 1980	981 (53.4%)	117 (6.4%)	227 (12.4%)	513 (27.8%)	1,838 (100%)
Population (Million) 2000	1,262 (52.7%)	127 (5.3%)	282 (11.8%)	722 (30.2%)	2,393 (100%)
Primary Energy (Mtoe) 1980	419 (13.5%)	347 (11.1%)	1,812 (58.2%)	537 (17.2%)	3,115 (100%)
Primary Energy (Mtoe) 2000	928 (19.0%)	525 (10.7%)	2,300 (47.1%)	1,134 (23.2%)	4,887 (100%)
CO_2 Emissions (Mt) 1980	413 (17.6%)	251 (10.7%)	1,307 (55.6%)	381 (16.1%)	2,352 (100%)
CO_2 Emissions (Mt) 2000	881 (19.0%)	328 (9.2%)	1,580 (44.4%)	2,191 (27.4%)	3,558 (100%)

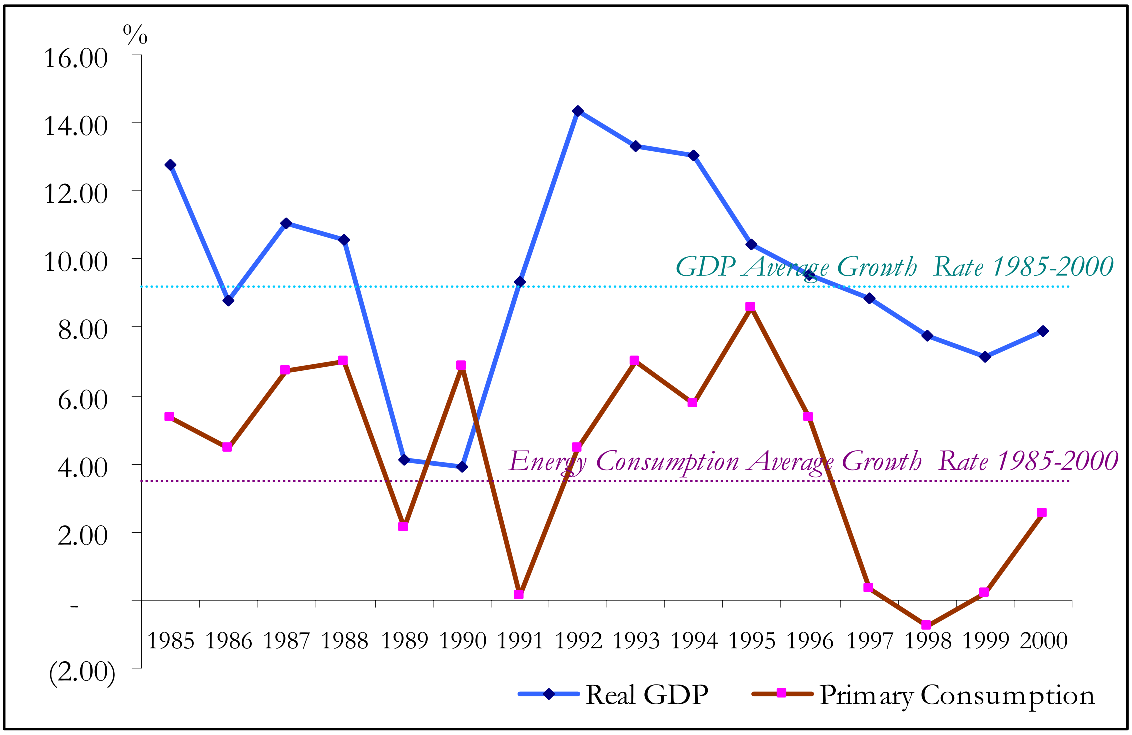
Source: IEEJ (2003). Carbon dioxide emissions are expressed in million tonnes of carbon.

[8] IEEJ (2003). If GDP is measured based on purchasing power parity, China now has the second largest GDP in APEC.

[9] Excluding Papua New Guinea

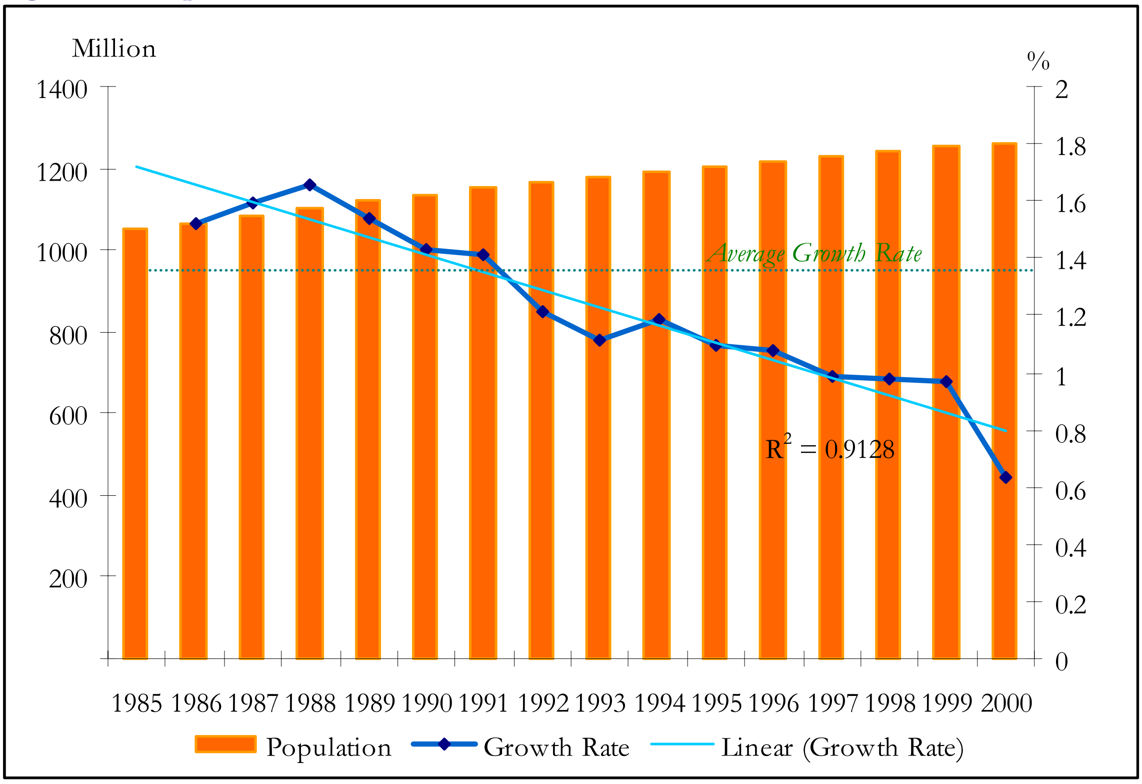
As shown in Figure 10, growth in China's primary energy consumption has followed growth in China's GDP over time, but energy use has consistently grown more slowly than GDP. As seen in Figure 11, China's population growth has slowed, from 1.2 percent per annum between 1985 and 2000 to just 0.6 percent in 2000. However, China's GDP and energy use are growing much faster.

Figure 10 Growth in China's GDP and Primary Energy Consumption, 1985-2000



Source: IEEJ (2003).

Figure 11 Population Growth Trends in China, 1985-2000



Source: IEEJ (2003).

Between 1980 and 2000, China's carbon dioxide emissions more than doubled, as did its energy consumption. However, the economy's GDP expanded six-fold over the same period. Hence, the energy intensity of the economy declined from 2,545 Mtoe to 892 Mtoe per million dollars of GDP. Nonetheless, carbon emissions per capita grew from 421 kg to 698 kg, as economic growth was associated with increased use of oil for transport and coal for electricity generation. Oil use in China nearly tripled from 88 Mt in 1980 to 246 Mt in 2002, while electricity generation grew five-fold from 301 TWh to 1,638 TWh and coal use doubled from 314 Mtoe to 663 Mtoe. China now consumes about 4 percent of all oil and 45 percent of all coal in the APEC region, while generating 16 percent of its electricity. While China is expected to remain self-sufficient in coal for some time to come, it has started to import growing amounts of oil and petroleum products.[10]

STUDY OVERVIEWS

This section reviews the methodology used, scenarios considered and energy projections made in each study examined. Studies by EIA, IEA, APERC, LBNL and Tsinghua are considered in turn.

ENERGY INFORMATION ADMINISTRATION (EIA)[11]

BACKGROUND AND METHODOLOGY

The Energy Information Administration's *International Energy Outlook 2003* examines energy trends in China and other economies. EIA's modelling specifies different rates of GDP growth and different government energy policies, including policies that affect energy efficiency, the energy intensity of GDP, energy consumption, and carbon dioxide emissions. The model used is the System for Analysis of Global Energy Markets, SAGE. The time horizon for the analysis is 2025.

ENERGY SCENARIOS FOR CHINA

EIA's projections are calibrated to assumptions about growth in population and GDP. Annual growth in China's GDP is assumed to be 6.2 percent in the business-as-usual (BAU) case, 7.2 percent in the high-growth case, and 3.6 percent in the low-growth case. By comparison, world GDP growth is assumed to be slower, at annual rates of 3.1 percent in the business-as-usual case, 4.2 percent in the high-growth case, and 2.0 percent in the low-growth case.

PROJECTED ENERGY CONSUMPTION IN CHINA

EIA projects that China's energy consumption will grow an annual average of 3.5 percent in the BAU case, 4.2 percent in the high-growth case, and 1.8 percent in the low-growth case. In the BAU case, demand for oil is projected to grow 3.3 percent per annum and electricity use is projected to grow 4.3 percent per annum. Details of EIA projections by fuel are shown in Table 2.

Table 2 Energy Information Administration Projections of China's Energy Use

	Energy Consumption in 2025			Annual Growth 2000-2025		
Fuel	Low	BAU	High	Low	BAU	High
Oil	7.4 Mbpd	10.9 Mbpd	12.9 Mbpd	1.7 %	3.3 %	4.0 %
Electricity	2,418 TWh	3,596 TWh	4,289 TWh	2.6 %	4.3 %	5.1 %
Natural Gas	4.2 Tcf	6.1 Tcf	7.5 Tcf	6.2 %	7.9 %	8.8 %
Coal	1,799 Mt	2,917 Mt	3,476 Mt	1.1 %	3.2 %	3.9 %
Nuclear	139 TWh	154 TWh	178 TWh	9.2 %	9.7 %	10.4 %
Renewable	5.9 Quad	6.4 Quad	7.2 Quad	3.3 %	6.4 %	4.1 %
Total Energy	1,520 Mtoe	2,288 Mtoe	2,708 Mtoe	1.8 %	3.5 %	4.2 %

Source: Energy Information Administration (2003). Quad =1 quadrillion Btu. Renewable category includes hydropower.

[10] BP (2003). NBS (2003b). IEEJ (2003).

[11] Energy Information Administration (2003).

ASIA PACIFIC ENERGY RESEARCH CENTRE (APERC)[12]

BACKGROUND AND METHODOLOGY

The Asia Pacific Energy Research Centre's *Energy Demand and Supply Outlook 2002* projects demand and supply for each of the 21 economies in the APEC region, including China, as well as for the APEC region as a whole. APERC's modelling incorporates economy-specific rates of growth in population and GDP, as well as assumptions about the energy intensity of GDP and the carbon intensity of GDP for each APEC economy. The forecasting model used is the Long-range Energy Alternative Planning System (LEAP). The time horizon for the projections is 2020.

ENERGY SCENARIOS FOR CHINA

APERC's projections are calibrated to assumptions about population and GDP growth, as well as energy intensity and carbon intensity. In the BAU scenario, China's GDP is assumed to grow an average of 7.2 percent per annum from 1999 through 2020, as its population grows 0.7 percent per annum. The energy intensity and carbon intensity of China's GDP are assumed to decline at average annual rates of 4.1 and 4.0 percent, respectively, as energy use in the economy becomes more efficient and the use of lower-carbon energy sources expands. Nonetheless, with sustained economic growth, China's carbon dioxide emissions per capita would grow 2.2 percent annually over the same period under the analytic assumptions made.

PROJECTED ENERGY CONSUMPTION IN CHINA

APERC projects that China's final energy consumption will grow at 2.7 percent per annum through 2020. The fastest growth is expected to occur in transport, at an average of 5.3 percent per year, while residential energy use grows just 3.2 percent per year and industrial energy use grows just 2.7 percent per year. But industry is still projected to account for 46 percent of energy use in 2020, while buildings account for 30 percent and transport for 24 percent. In terms of the fuel mix, coal's share is projected to decline from 57 percent in 1999 to 51 percent in 2020, while oil's share grows from 19 to 26 percent. The share of natural gas is projected to grow from 2.4 to 7.1 percent over the same period, while the share of nuclear power grows from 0.4 to 2.0 percent.

INTERNATIONAL ENERGY AGENCY (IEA)[13]

BACKGROUND AND METHODOLOGY

The International Energy Agency's *World Energy Outlook 2002* projects energy needs in China and other regions of the world through 2030. The World Energy Model specifies rates of growth in GDP and energy intensity of GDP for each major region.

ENERGY SCENARIOS FOR CHINA

IEA's projections of energy use are keyed not only to assumptions about GDP but also to various assumptions about alternative energy policies. The policy options considered include options for improving energy efficiency, boosting renewable energy development and limiting impacts on the environment that are discussed in China's Tenth Five-Year Plan for 2001-2005. During the period from 2000 through 2030, in view of the boost that is likely to be given to China's economy from membership in the World Trade Organisation, GDP is assumed to grow 4.8 percent annually, while population is assumed to grow just 1.1 percent per year.

PROJECTED ENERGY CONSUMPTION IN CHINA

IEA projects that China's final energy demand will grow 2.7 percent per year. The transport sector's share of demand is projected grow from 15 percent in 2000 to 23 percent in 2030 due to 4.4 percent yearly growth stemming from booming road transport. Electricity consumption is projected to grow 4.2 percent yearly, or at about the same pace as GDP, as power demand is driven by rising personal incomes, commercial enterprise and industrial output. Coal's share of the fuel mix is projected to fall from 69 percent in 2000 to 60 percent in 2030, while oil's share grows from 24 to 27 percent, nuclear power's from 3 to 7 percent, and that of gas from 0.4 to 3 percent.

---

12 Asia Pacific Energy Research Centre (2002b).

13 International Energy Agency (2002b).

TSINGHUA UNIVERSITY[14]

BACKGROUND AND METHODOLOGY

Tsinghua developed an optimisation model that incorporates the Long-range Energy Alternative Planning System (LEAP). The model incorporates specific exogenous assumptions about energy supply, production and imports. The time horizon for the projections is 2030.

ENERGY SCENARIOS FOR CHINA

Tsinghua's study focuses on the fuel mix of energy supply in a BAU case and two alternative cases which each would reduce carbon emissions by 10 percent from that case. In an "externally-oriented" scenario, there is greater reliance on importing low-carbon fuels like natural gas and importing electricity through regional cooperation in Northeast Asia. In an "internally-oriented" case, with less regional cooperation, there is greater reliance on domestic renewable and nuclear energy. GDP is assumed to grow 6.7 percent yearly, about as projected in the Tenth Five Year Plan.

PROJECTED ENERGY CONSUMPTION IN CHINA

Tsinghua projects that China's final energy consumption will roughly double from 1,246 million tce in 1999 to 2,424 million tce in 2030. In 2030, industry is projected to account for 41 percent of energy use, the residential sector for 27 percent, transport for 20 percent, and agriculture and services for 6 percent each. In the BAU case, coal accounts for 38 percent of the end-use fuel mix and oil for 33 percent. But in the externally-oriented case, natural gas is imported to replace other fuels, gaining a 10 percent share of the end-use fuel mix so that coal's share falls to 35 percent and oil's share falls to 29 percent. In the internally-oriented scenario, renewable energy gains a 16 percent share and nuclear power gains a 12 percent share, so that coal's share again falls to 35 percent while oil's share falls only slightly to 32 percent. In the BAU and externally-oriented cases, in contrast, renewables make up only 12 percent of the fuel mix and nuclear energy just 1 percent.

As hydroelectric and gas-fired power in China are developed, the dominant role of coal in power production is likely to recede somewhat. In its BAU scenario, Tsinghua projects that hydropower's share of fuel use for electricity generation will grow from 18 percent in 1999 to 24 percent in 2030, while gas grows from less than 1 percent to 21 percent of the mix and coal's share falls from 80 percent to 53 percent. In the externally-oriented scenario, the gas share of fuel use for generation rises to 48 percent and coal's share falls to 24 percent. In the internally-oriented case, nuclear power's share of fuel use for electricity generation in 2030 rises to 40 percent and coal's falls to 34 percent. As compared with the other studies, Tsinghua's makes very aggressive assumptions about nuclear and gas-fired power.

LAWRENCE BERKELEY NATIONAL LABORATORY (LBNL)[15]

BACKGROUND AND METHODOLOGY

This study summarises several other studies that examine the relationship between China's energy consumption and carbon dioxide emission. The idea was to focus on policies that could limit energy consumption and carbon emissions. The main studies examined are as follows:

- Asian Development Bank (ADB) and State Science and Technology Commission (SSTC): *National Response Strategy for Global Climate Change: People's Republic of China;*
- United Nations Development Programme (UNDP), Chinese Government and World Bank: *China: Issues and Options in Greenhouse Gas Emission Control;*
- UNDP and National Environmental Protection Agency (NEPA): *Incorporation of Environmental Considerations in Energy Planning in the People's Republic of China;*
- ADB and UNDP: *Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS);*
- US Department of Energy and SSTC: *China Climate Change Country Study.*

[14] Guo (2003). Nuclear and hydropower plants are assumed to be 30% efficient in calculating primary fuel use shares.

[15] Sinton and Ku (2000).

ENERGY SCENARIOS FOR CHINA

Most of the scenarios project energy demand based on assumptions about GDP growth and government policies to boost energy efficiency and limit carbon dioxide emissions. The authors note that China's energy intensity has declined over time, in part due to carbon-limiting policies.

PROJECTED ENERGY CONSUMPTION IN CHINA

As shown in Table 3, each study examined finds that carbon dioxide emissions policies reduce growth in energy use and carbon emissions substantially and by similar amounts. While there are costs associated with emissions reductions, they are offset to a large degree by energy savings.

Table 3 Annual Growth of Energy Use and Carbon Emissions in China According to Various Studies Reviewed by Lawrence Berkeley National Laboratory

Study	Timeline	Business as Usual Cases		Carbon Dioxide Control Cases	
		Primary Energy	Carbon Dioxide	Primary Energy	Carbon Dioxide
National Response Strategy	1990-2050	3.1%	2.6%	2.7%*	2.1%*
Issues and Options	1990-2020	4.1%	3.7%	3.6%	2.3%
Environmental Considerations	1990-2020	3.2%	3.1%	2.8%	2.7%
ALGAS	1990-2020	3.7%	3.7%	3.0%	2.9%
Country Study	1990-2030	3.3%	3.2%	2.4%	1.9%

Source: Sinton and Ku (2000). Growth rates are approximate. * For scenario of Accelerated Policy, Low GDP Growth

COMPARISON OF STUDY SCENARIOS AND PROJECTIONS

COMPARISON OF GDP GROWTH SCENARIOS

Some of the key assumptions of each study described above are compared in Table 4. All of the studies have very similar assumptions about the rate of population growth, which is well understood from demographic analysis. The business-as-usual scenarios mostly postulate growth of around 7 percent per annum in GDP, in accord with the expectation in the Tenth Five Year Plan that output should quadruple by 2020, though the IEA assumes a much lower rate of 4.8 percent, apparently reflecting skepticism about China's ability to sustain rapid growth over the longer term. High-growth scenarios assume only slightly higher GDP growth than the BAU cases, from 6.5 to 7.2 percent per annum. Low-growth cases assume GDP growth of 3.6 to 6.0 percent per annum.

Table 4 Annual Growth of China's Population and GDP in Various Scenarios

Study	Timeline	Population	Low GDP	BAU GDP	High GDP
APERC Outlook 2002	1999-2020	0.7%	N/A	7.2 %	N/A
EIA Annual Outlook 2003	2001-2025	0.6%	3.6%	6.2%	7.2%
IEA World Energy Outlook 2002	2000-2030	0.5%	N/A	4.8%	N/A
Tsinghua University	1999-2030	0.6%	N/A	6.7%	N/A
National Response Strategy	1990-2050	0.6%	5.8%	N/A	6.5%
Issues and Options	1990-2020	0.6%	5.8%	7.3%	N/A
Environmental Considerations	1990-2020	0.6%	N/A	6.8%	N/A
ALGAS	1990-2020	0.9%	N/A	7.3%	N/A
Country Study	1990-2030	0.8%	6.0%	7.0%	N/A

Sources: Sinton and Ku (2000), APERC (2002), IEA (2002), Guo (2003), EIA (2003).

COMPARISON OF ENVIRONMENTAL SCENARIOS

The studies by Chinese researchers focus on the consequences of energy consumption for carbon dioxide emissions and on policies for limiting such emissions. Policy measures considered include importing low-carbon energy (natural gas and hydropower), reducing the carbon intensity of the energy mix (by developing nuclear power and renewables), and improving energy efficiency. The studies by APERC and IEA, which are broader in nature and focus less exclusively on environmental matters, include only one scenario each for carbon-limiting energy policies.

COMPARISON OF PROJECTED ENERGY DEMAND BY SECTOR

The APERC, IEA and Tsinghua studies break down final energy demand projections by end-use sector. As shown in Table 5, the three studies project that total final energy demand in China will grow between 2.2 percent and 2.7 percent per annum. APERC and Tsinghua project that final demand will grow only about one-third as fast as GDP, while IEA projects it will grow a little over half as fast. APERC projects the transport sector will account for nearly one-sixth of final energy demand by 2020, while IEA and Tsinghua project it will account for a fifth or more by 2030. The industrial share, while declining, should still account for more than two-fifths of demand in 2030.

Table 5 Projections of Final Energy Demand Growth and Shares by Sector in China

End-Use Sector	APERC 1999-2020			IEA 2000-2030			Tsinghua 1999-2030		
	Annual Growth	2020 Mtoe	2020 Share	Annual Growth	2030 Mtoe	2030 Share	Annual Growth	2030 Mtoe	2030 Share
Industry	2.7%	605	46%	1.9%	553	43%	1.6%	696	41%
Transport	5.3%	205	16%	4.1%	236	23%	4.0%	339	20%
Residential	1.5%	397	30%	3.1%	217	17%	1.8%	464	27%
Commercial	4.7%	73	5%	4.8%	111	9%	2.8%	97	6%
Others	3.2%	43	3%	1.6%	97	8%	4.1%	101	6%
Total	**2.7%**	**1,322**	**100%**	**2.6%**	**1,264**	**100%**	**2.2%**	**1,697**	**100%**

Sources: APERC (2002b), IEA (2002), Guo (2003). Tsinghua figures are larger since they include non-commercial energy.

COMPARISON OF PROJECTED ENERGY DEMAND BY FUEL

In terms of the split of primary energy demand among various fuels, the studies widely diverge. As shown in Table 6, the projections of overall growth in primary energy demand are quite close, from 2.8 to 3.6 per year through 2020 and 2.7 to 3.1 percent per year through 2030. There is also broad agreement that natural gas and nuclear power will grow rapidly from a small base. However:

- The projected share of oil varies from 26 percent according to APERC to 43 percent according to EIA in 2020, and from 27 percent according to IEA to 41 percent according to Tsinghua in 2030.
- Coal's projected share, meanwhile, varies from 23 percent in EIA's projection to 51 percent in APERC's projection for 2020 and from 20 percent in Tsinghua's projection to 60 percent in IEAs projection for 2030.
- There are likewise major differences in the projected share of natural gas, which are 7 percent for APERC and 17 percent for EIA in 2020 and 7 percent for IEA and 27 percent for Tsinghua in 2030.
- The estimates of nuclear power's share of the fuel mix range from 2 to 9 percent in projections for 2020 and from 3 to 6 percent in projections for 2030.
- Hydropower and other renewables are projected to account for 8 to 14 percent of primary demand in the 2020 projections and 5 to 6 percent in the 2030 projections.

Table 6 Projections of Primary Energy Demand Growth and Shares by Fuel in China

Fuel	APERC 1999-2020			EIA 2000-2020			IEA 2000-2030			Tsinghua 1999-2030		
	Annual Growth	2020 Mtoe	2020 Share	Annual Growth	2020 Mtoe	2020 Share	Annual Growth	2030 Mtoe	2030 Share	Annual Growth	2030 Mtoe	2030 Share
Oil	4.3%	497	26%	3.3%	504	43%	3.0%	578	27%	4.9%	576	41%
Coal	2.2%	990	51%	3.3%	1,170	23%	2.2%	1,278	60%	2.3%	1,049	20%
Gas	8.3%	138	7%	7.4%	121	17%	5.5%	151	7%	11.6%	183	27%
Nuclear	11.6%	39	2%	10.5%	11	9%	9.3%	63	3%	5.0%	10	6%
Renewable	6.9%	283	14%	4.6%	149	8%	3.8%	63	5%	1.2%	256	6%
Total	**2.8%**	**1,947**	**100%**	**3.6%**	**1,955**	**100%**	**2.7%**	**2,133**	**100%**	**3.1%**	**2,078**	**100%**

Sources: APERC (2002b), EIA (2003), IEA (2002), Guo (2003).

The studies reviewed by Lawrence Berkeley National Laboratory are in broad agreement about how China's fossil fuel use will be divided. As shown in Table 7, the studies project that coal will still account for 71 percent to 77 percent of fossil fuel demand in China in 2020, while oil will account for 17 to 22 percent and gas for just 5 to 7 percent. The oil share increases due to growing demand for road transport, while the gas share rises due to some gas use for electricity generation.

Table 7 China's Fossil Fuel Supply Mix in 2020 According to BAU Scenarios in Various Studies Reviewed by Lawrence Berkeley National Laboratory

Study	Total Supply	Share of Fossil Fuel Mix		
		Coal	Oil	Gas
National Response Strategy	2,100 Mtoe	73%	20%	6%
Issues and Options	1,820 Mtoe	74%	21%	5%
Environmental Considerations	1,470 Mtoe	71%	22%	7%
ALGAS	1,400 Mtoe	77%	18%	5%
Country Study	1,820 Mtoe	76%	17%	7%

Source: Sinton and Ku (2000)

Projections of future oil demand in China are of particular interest since rapid expansion of road transportation, which relies on oil products almost exclusively, will be leading to a major expansion of China's oil imports, with impacts on oil markets in the rest of APEC and the world. That is the main focus of the following three chapters of this report. Regarding China's oil demand in 2020, projections vary enormously due to uncertainty as to how long transport will keep growing rapidly:

- EIA projects just 467 Mtoe of final oil demand, near the low end of the range.[16]
- APERC projects 497 Mtoe of final oil demand, near the middle of the range.[17]
- IEA projects 550 Mtoe of final oil demand, toward the upper end of the range.[18]
- Tsinghua projects between 497 Mtoe and 568 Mtoe of final oil demand.[19]
- China's Energy Research Institute (ERI) has three scenarios projecting 401 Mtoe, 483 Mtoe and 526 Mtoe of oil use, respectively.[20]
- The Development Research Centre (DRC) of China's State Council also has three scenarios that respectively project 447 Mtoe, 557 Mtoe and 614 Mtoe of oil use.[21]

PROJECTED ELECTRICITY DEMAND

Projections of future electricity demand in China are also of special interest since the amount and fuel mix of electricity generation will affect gas and coal markets and the environmental impacts of fossil fuel use. These are the main focus of the final three chapters of this report. Figure 12 shows some recent projections of China's electricity demand. In 2020, IEA projects 2,254 TWh of demand and Tsinghua's projection of 2,478 TWh is just one-tenth higher, while APERC and EIA projections of 2,987 TWh and 2,986 TWh, respectively, are one-third higher. Yet by 2030, IEA and Tsinghua projections diverge enormously: IEA's projection of 4,813 TWh, with 7.9 percent annual growth from 2020, is two-thirds higher than Tsinghua's projection of 2,852 TWh, which assumes much slower 1.4 percent yearly growth from 2020. The difference may have to do with what drives growing power demand: IEA assumes it is mainly households with growing incomes, while Tsinghua assumes it is mainly heavy industry. Also, as shown in Figure 13, IEA

16 EIA (2003).

17 APERC (2002b).

18 IEA (2000).

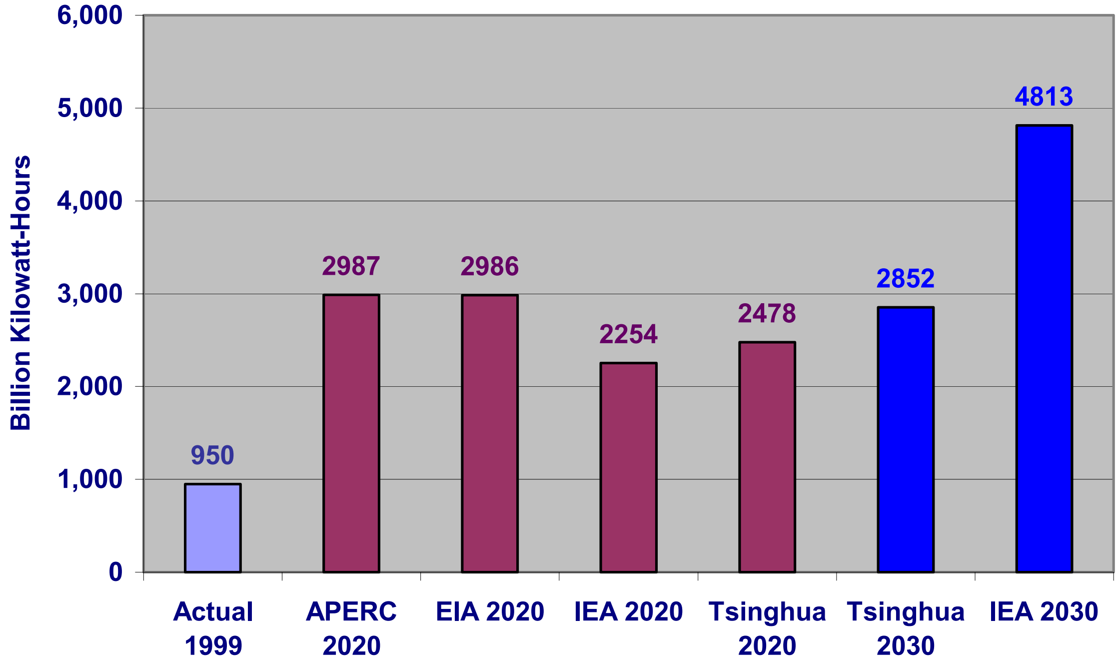
19 Guo (2003).

20 Zhou, D. (2003)

21 DRC (2003).

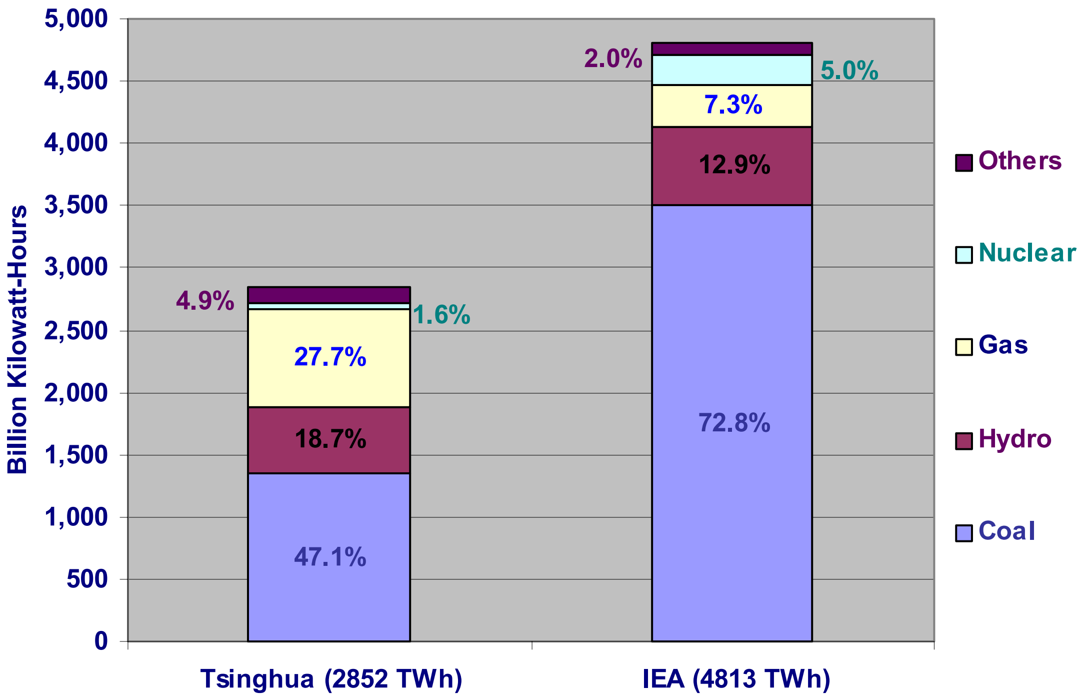
projects that 73 percent of electricity will be generated from coal, while Tsinghua projects that just 47 percent will be, due to aggressive assumptions about the future role of natural gas.[22]

Figure 12 Alternative Projections of Electricity Demand in China, 2020 and 2030



Sources: APERC (2002b), EIA (2002), IEA (2002b), Guo (2003).

Figure 13 Two View of China's Electric Generating Mix in 2030



Sources: IEA (2002a), Guo (2003).

22 APERC (2002b), EIA (2002), IEA (2002a), Guo (2003).

TRENDS IN CHINA'S TRANSPORTATION SECTOR

INTRODUCTION

In China, as in most of the rest of the world, oil demand is being driven by transportation. With rapid economic growth and aggressive expansion of transportation infrastructure, China saw a four-fold increase in freight traffic and a six-fold increase in passenger traffic from 1980 to 2000. On highways, growth has been even more dramatic: eight-fold for freight traffic and nine-fold for passenger traffic. If China's economy quadruples in size between 2000 and 2020, as foreseen in the government's Eleventh Five-Year Plan, China's demand for road transport and oil products could further triple by 2020. Together with continued growth in oil demand elsewhere in the APEC region, this could lead to a substantial increase in oil prices over the longer term. This chapter reviews recent trends in China's freight and passenger transport and how they affect energy use. The following chapters then assess the impacts on China's imports of crude oil and oil products, as well as policy options for moderating growth in oil use and enhancing China's oil supply security.

OVERVIEW OF TRANSPORTATION DEVELOPMENT IN CHINA

INFRASTRUCTURE AND TOTAL TRAFFIC

Transportation has been one of the fastest-growing economic sectors in China. A complex system of highways, railways, waterways, civil aviation and pipelines moves more than 10 billion people and 10 billion tonnes of goods every year. During the 1980s and 1990s, the economy grew faster than the capacity of the transportation network, which thus became a bottleneck constraining economic development. More recently, an aggressive programme of investment in transportation infrastructure has relieved some of the bottlenecks but has also boosted demand for cars and trucks.

Table 8 shows the development of China's transportation infrastructure and traffic demand in the last two decades. From 1980 through 2002, as the length of available highways doubled, total freight traffic volume grew four-fold, total passenger traffic volume grew six-fold, and civilian air traffic grew eight-fold. When China reformed its residential registration system in the 1980s by no longer requiring people to obtain government approval for internal travel, growth in passenger travel accelerated. More and more people travelling for business, job-seeking, or recreation have increasingly relied on highways for trips within cities and adjacent suburban areas. Growth in highway freight and passenger traffic has meant rapid growth in oil product consumption.[23]

Table 8 Historical Development of Transportation in China, 1980-2002

Transport System Indicator	1980(a)	2002 (b)	2002/1980
Railways in operation (thousand km)	49.9	71.9	1.44
Highways (thousand km)	883.3	1,765.2	2.00
Navigable inland waterways (thousand km)	108.55	121.6	1.12
Civil aviation (thousand km)	195.3	1,637.7	8.39
Pipelines (thousand km)	8.7	29.8	3.43
Passenger traffic volume (billion person-km)	228.1	1,412.6	6.19
Freight traffic volume (billion tonne-km)	1,202.6	5,054.3	4.20

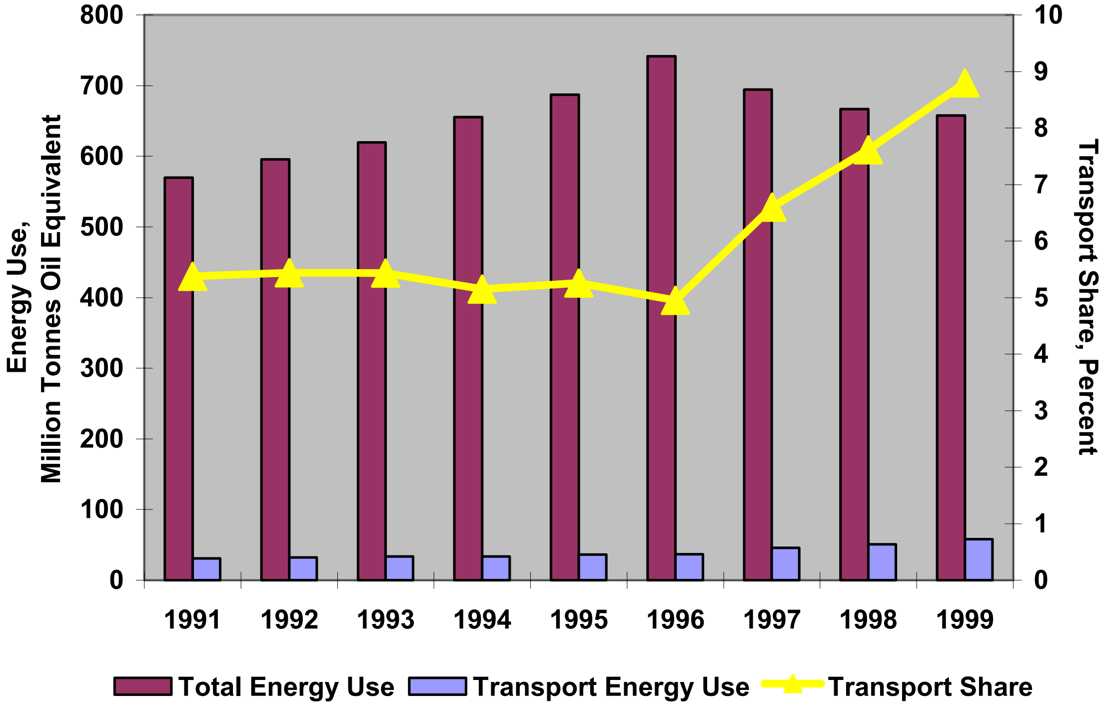
Source: China Transportation Association (2003). Notes: (a) Excludes private business. (b) Includes private business.

[23] China Transportation Association (2003), pages 573-579. National Bureau of Statistics (2002), page 251.

ENERGY CONSUMPTION FOR TRANSPORT IN CHINA

Figure 14 shows China's total final energy consumption, energy consumption for transport, and transport energy consumption as a share of total consumption based on official published data. While total energy consumption has declined in recent years, as market-based pricing has forced businesses to economise on energy use, energy use in transport has grown rapidly. Hence, the transport share of total energy use grew from under 5 percent in 1996 to nearly 9 percent in 1999.

Figure 14 The Growing Share of Transport in China's Energy Use, 1991-1999



Source: National Bureau of Statistics (1998) and (2001).

In the official data, energy consumption for transportation only covers energy use from enterprises whose main business is transport, excluding energy use for transport by other enterprises and individuals. This is thought by experts to be the most prominent deficiency in China's energy consumption figures.[24] Based on research in China and elsewhere, the actual transport share of energy use is up to 6 percentage points higher than shown in official published data, and the gap between statistical data and reality has grown over time. Table 9 summarizes some recent efforts to estimate the actual energy consumption for transport purposes in China.

Table 9 Comparative Estimates of Transport Energy Consumption Shares in China

Research Institute	Lawrence Berkeley National Lab, USA	APEC Energy Working Group	ERI, China	Tsinghua University, China	IEEJ, Japan
Year and Source of Data	1994 (a)	1997 (b,2)	1998 (c)	1999 (d,3)	2000 (e)
Estimated Transport Share of Final Energy Use	7%	7.1%	12%	13.6%	13.3%
Transport Share of Energy Use in Official data (1)	4.5%	6.6%	8.8%	7.2%	--
Difference (Percentage Points)	2.5%	0.5%	3.2%	6.4%	--

Sources: (a) Sinton and others (1996). (b) APEC (2002). (c) Zhou, D. (2003). (d) Guo (2003). (e) IEEJ (2003).

Notes: (1) National Bureau of Statistics. (2) Calorific value calculations. (3) Coal equivalent calculations.

[24] Sinton (2002).

The Institute of Comprehensive Transportation (ICT) of the National Development and Reform Commission developed energy consumption data for transportation as shown in Table 10. The ICT analysis shows that among the different transport modes, road transport consumes the greatest amount of energy. The share of energy use accounted for by highway transport grew roughly from 48 percent in 1990 to 68 percent in 2000, and most of this is in the form of oil. The share of civil aviation grew rapidly as well, on a much smaller base, from 2 percent to 5 percent.[25]

Table 10 Energy Consumption for Transport in China by Transport Mode, 1990-2000

Transport Mode:	Energy Consumption			Consumption Share		
	1990	2000	Ratio	1990	2000	Change
Railways	14,851 ktoe	13,017 ktoe	0.88	27.8 %	13.5 %	-14.2 %
Highways	25,495 ktoe	65,516 ktoe	2.57	47.6 %	68.1 %	+20.5 %
Waterways	11,407 ktoe	11,988 ktoe	1.05	21.3 %	12.5 %	-8.8 %
Civil Aviation	1,222 ktoe	5,090 ktoe	4.16	2.3 %	5.3 %	+3.0 %
Pipelines	550 ktoe	605 ktoe	1.10	1.0 %	0.6 %	-0.4 %
Total	53,524 ktoe	96,214 ktoe	1.80	100.0 %	100.0 %	0.0 %

Source: CERS (2002).

PASSENGER TRANSPORT TRENDS IN CHINA

HISTORICAL TRENDS IN PASSENGER TRANSPORT

As shown in Table 11 and Figure 15, passenger traffic in China has come to be increasingly dominated by cars for short trips and planes for long trips, as growing incomes have allowed more people to utilise these fast and comfortable means of travel. From 1980 through 2002, total passenger traffic grew over six-fold, from 228 billion to 1,413 billion person-km. Passenger highway traffic grew ten-fold, its share of total passenger traffic increasing from 32 percent to 55 percent. Passenger aviation traffic grew more than thirty-fold, its share of passenger traffic growing five-fold from under 2 percent to 9 percent. Railway passenger traffic, while nearly quadrupling in volume, saw its share of passenger traffic decline from 61 percent to 35 percent.[26] However, average annual growth in highway traffic share has slowed from 3.7 percent in the late 1980s to 1.9 percent in the early 1990s to 1.2 percent in the late 1990s to 0.9 percent between 2000 and 2002.

Table 11 Modal Volumes of Passenger Traffic in China (Billion Person-Kilometres)

Year	Railways	Highways	Waterways	Aviation	Total
1980	138.3 (60.6%)	73.0 (32.0%)	12.9 (5.7%)	4.0 (1.7%)	228.1 (100%)
1985	241.6 (54.5%)	172.5 (38.9%)	17.9 (4.0%)	11.7 (2.6%)	443.6 (100%)
1990	261.3 (46.4%)	262.1 (46.6%)	16.5 (2.9%)	23.0 (4.1%)	562.9 (100%)
1995	354.6 (39.4%)	460.3 (51.1%)	17.2 (1.9%)	68.1 (7.6%)	900.2 (100%)
2000	453.3 (37.0%)	665.7 (54.3%)	10.1 (0.8%)	97.1 (7.9%)	1,226.1 (100%)
2002	496.9 (35.2%)	780.6 (55.3%)	8.2 (0.6%)	126.9 (9.0%)	1,412.6 (100%)

Source: China Transportation Association (2003).

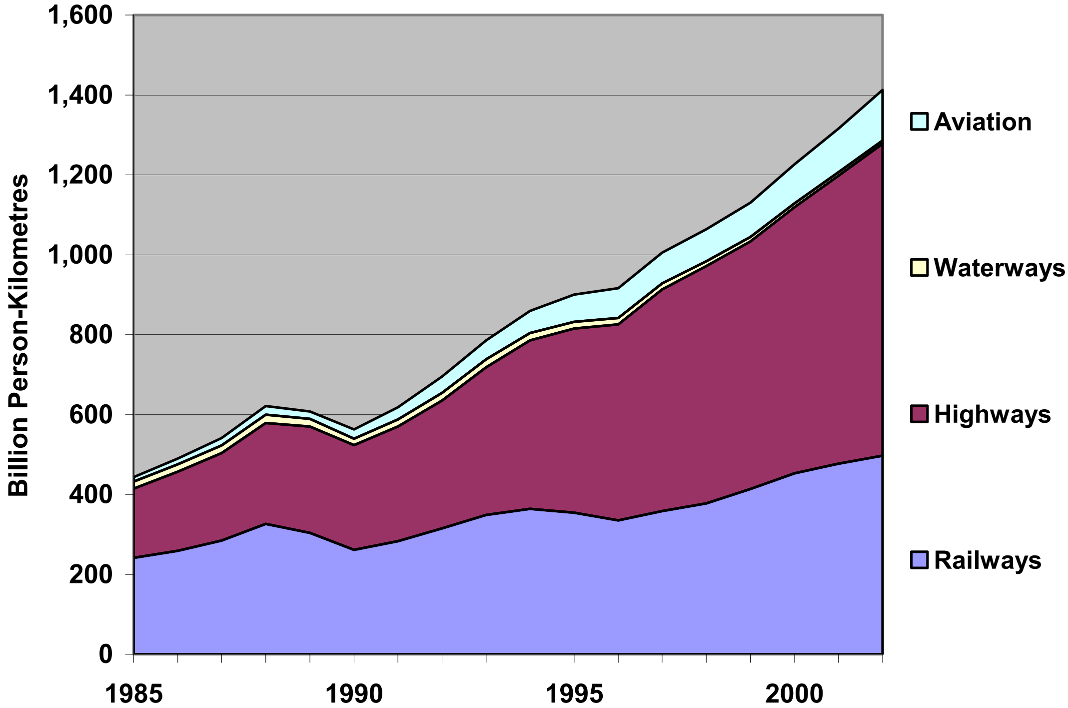
The shift toward highway and air traffic has been greatly facilitated by an extensive programme of infrastructure development. The government has sometimes relied on investment in transportation infrastructure to help maintain economic growth, both directly in terms of building the infrastructure and indirectly in terms of encouraging production and use of automobiles. As shown in Table 12, growth in available highways, expressways, and paved roads in general has been very rapid in the last decade. From 1990 through 2001, highways grew 65 percent and expressways

[25] CERS (2002).

[26] China Transportation Association (2003), page 579.

grew 80 percent. Paved roads in cities grew much faster in area (180 percent) than in length (85 percent), indicating that construction focused on wider roads useable by cars. The number of civilian airports increased by 52 percent. Railways, though, grew a much more modest 21 percent.[27]

Figure 15 Passenger Traffic Trends in China by Transport Mode, 1985-2002



Source: China Transportation Association (2003)

Table 12 Transportation Infrastructure Development in China, 1990-2001

Infrastructure Indicator	1990	1995	2000	2001	Absolute Annual Increase		
					1990-1995	1995-2000	2000-2001
Highway (thousand km)	1,028	1,157	1,403	1,698	26	49	295
Expressway and Class I to IV Highway (thousand km)	741	911	1,216	1,336	34	61	120
Paved Roads in Cities (000 km)	95	130	160	176	7	6	16
Paved Road Area in Cities (million square metres)	892	1,358	1,904	2,494	93	109	591
Paved Road per Capita in Cities (linear metres per person)	0.64	0.70	0.76	0.82	0.012	0.012	0.16
Paved Area per Capita in Cities (square metres per person)	6.0	7.3	9.1	11.6	0.26	0.36	2.50
Railway in Operation (000 km)	57.8	59.7	68.7	70.1	0.4	1.8	1.4
Number of Civilian Airports	94	139	139	143	9	0	4

Source: National Bureau of Statistics (2000). China Transportation Association (2000).

With incomes growing and with far more roads on which to travel, there has been enormous growth in the number of automobiles, especially privately-owned ones, as shown in Table 13. From 1990 through 2002, the number of civilian motor vehicles increased nearly four-fold, while the number of privately-owned vehicles (a subset of total civilian vehicles) increased about twelve-fold.[28] Of the overall increase in civilian vehicles, privately-owned vehicles accounted for 34

[27] NBS (2002), pages 364, 532-3, 558. China Transportation Association (2000), pages 97-107, 219.

[28] NBS (2002), page 552. NBS (2003a), page 146.

percent in the early 1990s, 66 percent in the late 1990s, and 77 percent between 2000 and 2002. Studies have shown that when the GDP per capita reaches $1,000, families start to buy cars in large numbers. GDP per capita has reached that level in large Chinese cities like Beijing, Shanghai, Guangzhou and Shenzhen, where much of the growth in civilian vehicle population has been seen.[29]

Table 13 Growth of Motor Vehicle Population in China, 1990-2002

Motor Vehicle Population	1990	1995	2000	2002	Absolute Annual Increase		
					1990-1995	1995-2000	2000-2002
Civilian Vehicles (thousand)	5,514	10,400	16,089	20,532	977	1,138	2,221
Private Vehicles (thousand)	816	2,500	6,253	9,690	337	751	1,718

Source: NBS (2003a). Civilian vehicle figures include motorcycles; privately-owned vehicle figures exclude them.

The enormous growth in automobile use has also been supported by the government's decision in 1984 to allow the use of private cars, which had previously been prohibited. Until the 1990s, about 70 percent of cars were sold to government agencies and 30 percent to businesses, with very few sold to households. Yet by 2001, the household share of cars sold had grown to 37 percent, exceeding the 34 percent share for government and the 29 percent share for business. The household share is even greater in major cities like Beijing where it has reached 60 percent.[30]

Growth in automobile ownership has been further assisted by China's decision in the 1990s to build a domestic automobile industry. This is part of an overall industrial strategy in which motor vehicle manufacturing has boosted the manufacture of aluminium, plastics, and machinery. While the domestic car industry has been developed through partnerships with major foreign automobile manufacturers, it is not envisioned that many cars made in China will be exported to other countries in the immediate future. Rather, it is anticipated that the domestic car market will have to support the rapidly-growing automobile industry. In the first quarter of 2003, total car sales exceeded 409,000 units, more than doubling from the same period in 2002. The auto industry has now become the fifth-largest industry in the economy in terms of sales. The dramatic growth of China's motor vehicle output is shown in Table 14. Between 1990 and 2002, motor vehicle production grew more than six-fold, as production of passenger cars grew by a factor of thirty.[31]

Table 14 Growth of Motor Vehicle Manufacturing in China, 1990-2002

Motor Vehicle Output	1990	1995	2000	2002	Absolute Annual Increase		
					1990-1995	1995-2000	2000-2002
Total Vehicles (thousand)	514	1,453	2,070	3,251	188	123	590
Passenger Cars (thousand)	35	337	607	1,092	60	54	242
Passenger Car Share	6.8%	23.2%	29.3%	33.6%	3.3%-point	1.2%-point	2.1%-point

Source: National Bureau of Statistics (2002) and (2003b).

FACTORS AFFECTING ENERGY USE IN PASSENGER TRANSPORT

Several key factors should continue affecting China's energy use in passenger transport:

- ***Growing Incomes:*** As incomes grow and living standards improve, more people are likely to afford the purchase of a private automobile, extending the trend toward greater volumes of highway traffic in the passenger transport mix.
- ***Urbanisation and Urban Transport Options:*** As growing numbers of people move to large cities for employment, more may be able to use urban mass transport options such as bus and subway systems, instead of or in addition to cars. Large cities may adopt traffic management policies such as road use taxes and parking fees that encourage people to utilise urban public transport options.

[29] Zhou, D. (2003).

[30] NBS (2002), pages 550-52.

[31] *Ibid.*, page 477.

- ***Long-Distance Travel Modes:*** Aviation looks poised to continue gaining market share in passenger traffic, related to its speed for long-distance travel. Jet fuel demand should thus grow substantially. While much air travel displaces far slower rail travel, high-speed railways may compete with aviation by around 2020.
- ***Vehicle Fuel Economy:*** As the number of vehicles grows, oil consumption in China will be increasingly influenced by vehicle size and efficiency, as measured in fuel economy (kilometres per litre of fuel). Regulatory measures such as gasoline taxes, fuel economy standards, taxation of inefficient vehicles, and financial incentives for the purchase of efficient vehicles could affect fuel economy trends.

FREIGHT TRANSPORT TRENDS IN CHINA

HISTORICAL TRENDS IN FREIGHT TRANSPORT

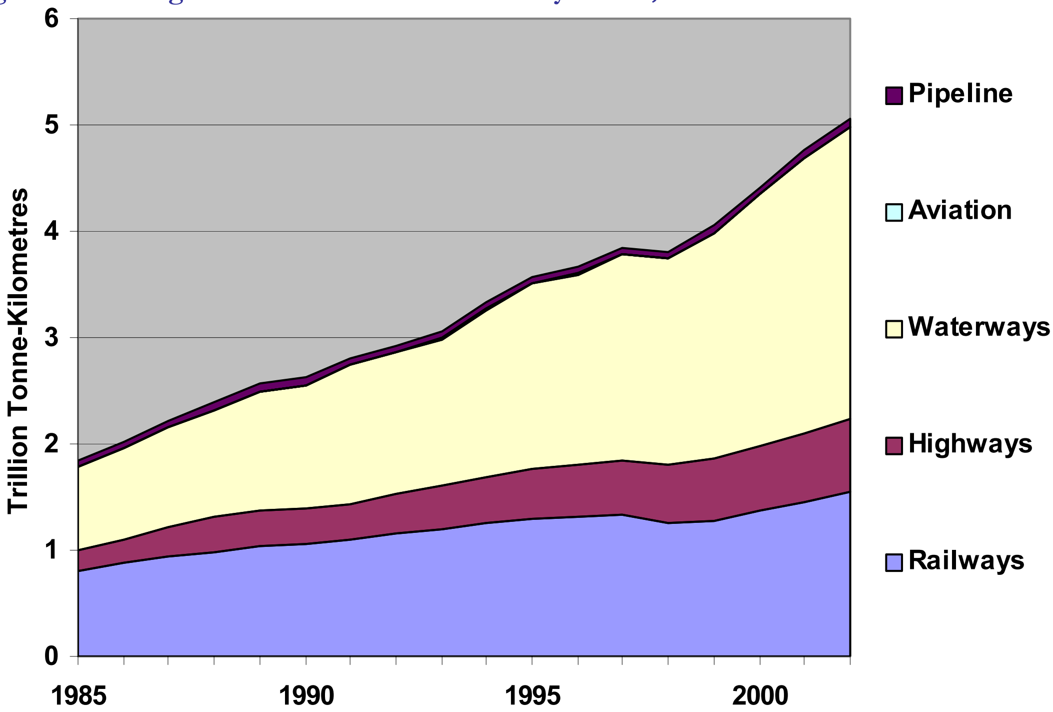
As seen in Table 15 and Figure 16, more than half of China's freight traffic occurs on waterways. From 1980 through 2002, total freight traffic grew more than four-fold, from 1.2 trillion tonne-km to 5.1 trillion tonne-km. Freight waterway traffic grew more than five-fold, increasing its share of overall freight traffic from 42 percent to 54 percent. Freight highway traffic grew nearly nine-fold, its share of total freight traffic doubling from 6 percent to 13 percent. Railway freight traffic nearly tripled in volume, but its share of freight traffic fell from 48 percent to 31 percent.

Table 15 Modal Volumes of Freight Traffic in China (Billion Tonne-Kilometres)

Year	Railways	Highways	Waterways	Aviation	Pipeline	Total
1980	571.7 (47.5%)	76.4 (6.4%)	505.3 (42.0%)	0.1 (0.0%)	4.9 (0.4%)	1,202.6 (100%)
1985	812.6 (44.2%)	190.3 (10.4%)	772.9 (42.1%)	0.4 (0.0%)	60.3 (3.3%)	1,836.5 (100%)
1990	1,062.2 (40.5%)	335.8 (12.8%)	1,159.2 (44.2%)	0.8 (0.0%)	62.7 (2.4%)	2,620.8 (100%)
1995	1,287.0 (36.0%)	469.5 (13.1%)	1,755.2 (49.1%)	2.2 (0.1%)	59.0 (1.7%)	3,573.0 (100%)
2000	1,366.3 (30.9%)	612.9 (13.9%)	2,373.4 (53.7%)	5.0 (0.1%)	63.6 (1.4%)	4,421.3 (100%)
2002	1,551.6 (30.7%)	678.3 (13.4%)	2,751.1 (54.4%)	5.2 (0.1%)	68.3 (1.4%)	5,054.3 (100%)

Source: China Transportation Association (2003).

Figure 16 Freight Traffic Trends in China by Mode, 1985-2002



Source: China Transportation Association (2003).

Of the total 2,751 billion tonne-km of freight moved on China's waterways in 2002, 79 percent was ocean-going cargo, principally destined for foreign trade, while 16 percent was coastal cargo and 5 percent internal river cargo, both destined mainly for domestic commerce.[32] With economic globalisation, oceanic navigation should retain a large percentage of total freight traffic. If ocean-going freight traffic is excluded, as in Table 16, it is seen that domestic freight transport continues to be dominated by railways, while the importance of highway freight transport is growing rapidly. Whereas railways' share of total freight traffic has fallen to 31 percent, their share of domestic freight traffic has grown to 54 percent. While the highway share of overall freight traffic has risen to 13 percent, the highway share of domestic freight traffic has more than doubled to 24 percent.[33]

Table 16 Domestic Freight Traffic in China by Mode (Billion Tonne-Kilometres)

Year	Railways	Highways	Waterways	Aviation	Pipeline	Total
1980	571.7 (71.0%)	76.4 (9.5%)	152.1 (18.9%)	0.1 (0.0%)	4.9 (0.6%)	805.3 (100%)
1985	812.6 (62.3%)	190.3 (14.6%)	240.0 (18.4%)	0.4 (0.0%)	60.3 (4.6%)	1,303.6 (100%)
1990	1,062.2 (58.8%)	335.8 (18.6%)	345.1 (19.1%)	0.8 (0.0%)	62.7 (3.5%)	1,806.7 (100%)
1995	1,287.0 (53.7%)	469.5 (19.6%)	577.2 (24.1%)	2.2 (0.1%)	59.0 (2.5%)	2,395.0 (100%)
2000	1,366.3 (50.3%)	612.9 (22.6%)	666.2 (24.5%)	5.0 (0.2%)	63.6 (2.3%)	2,714.0 (100%)
2002	1,551.6 (53.9%)	678.3 (23.5%)	577.8 (20.1%)	5.2 (0.2%)	68.3 (2.4%)	2,881.1 (100%)

Sources: China Transportation Association (2000) and (2001). National Bureau of Statistics (1993).

Figure 17 Geographic Regions of China

Source: China Geographic Agency

[32] China Transportation Association (2003), page 637. CTA (2001), page 614. CTA (2000), page 487.

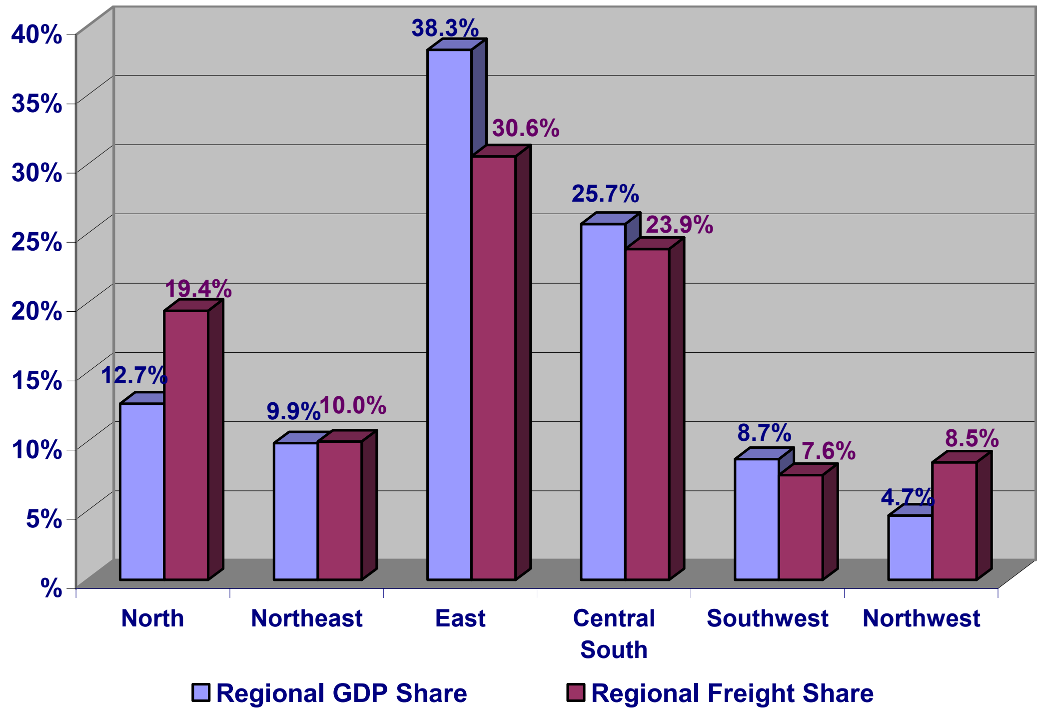
[33] *Ibid.* China Transportation Association (2001), page 614. CTA (2000), page 487. NBS (1993), page 519.

About two-thirds of railway freight traffic involves the shipment of basic materials like coal, petroleum, iron, steel, minerals, lumber and grain. Since the share of basic goods in railway traffic steadily remained between 60 and 70 percent from 1985 to 2001, this pattern seems likely to persist. With development of mine-mouth coal-fired power plants, extension of power grid inter-connections, and reduced direct coal use by homes and businesses, coal freight volumes could decline over time. But in view of the broad range of products carried by rail, as well as the recent expansion of interregional rail links to facilitate shipment of energy and minerals from west to east, the long-run role of railways in domestic freight transport seems assured.[34]

The bulk of China's freight transport occurs in the East and Central South regions, which have relatively high levels of income per capita. As shown in Figure 18, which compares regional shares of China's GDP and freight traffic in 2002, these regions together account for nearly two-thirds of China's output and over half of its domestic freight traffic. The less prosperous North, Northeast, Southwest and Northwest, whose economies depend largely on the shipment of raw materials east and south, together account for only a third of GDP and less than half of domestic freight.[35]

The East and Central South regions, with long rivers and coastlines, also account for most of China's waterway traffic, as shown in Figure 19. The East, in which 43 percent of freight is shipped by water, accounts for 64 percent of national water traffic. The Central South, where 24 percent of freight goes by water, accounts for 28 percent of national waterway traffic. In the North, Northeast and Northwest, about two thirds of freight traffic takes place by rail. Highways play an important role in freight transport in all regions, ranging from 17 percent in the Northeast to 35 percent in the Southwest, as they are everywhere suited to delivery of products over shorter distances.[36]

Figure 18 Regional Shares of China's GDP and Domestic Freight Traffic in 2002



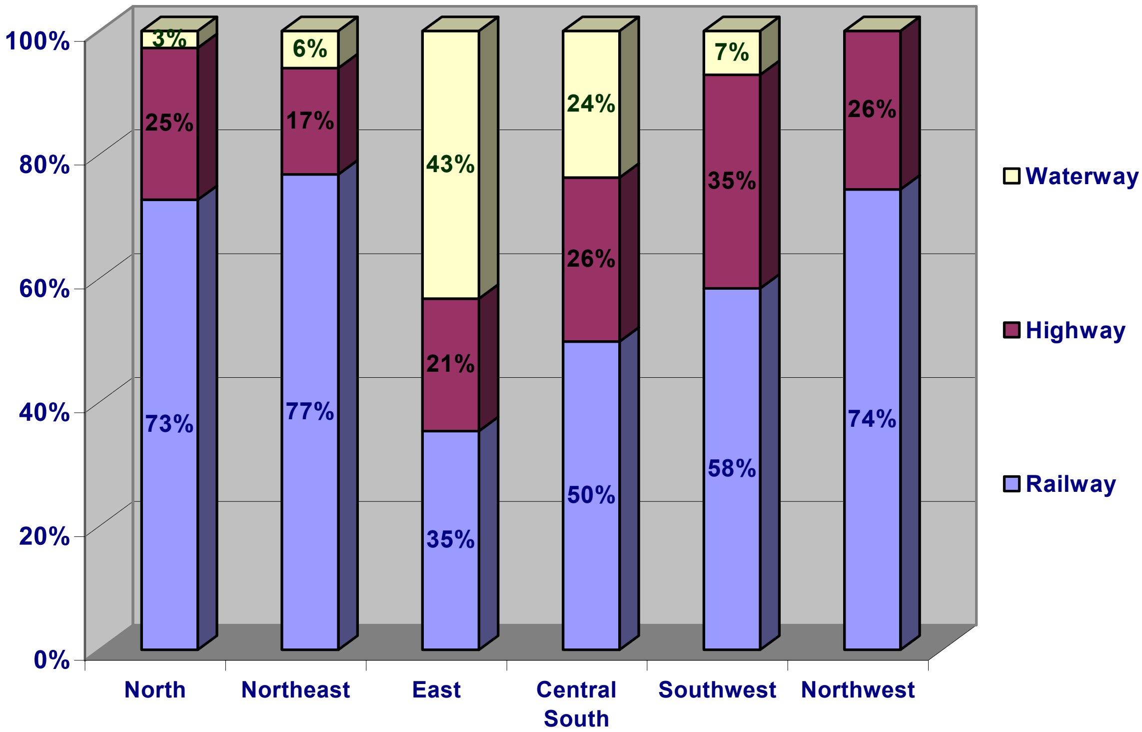
Source: National Bureau of Statistics (2003b).

[34] NBS (2002), pages 544-5.

[35] NBS (2003a), pages 23, 145.

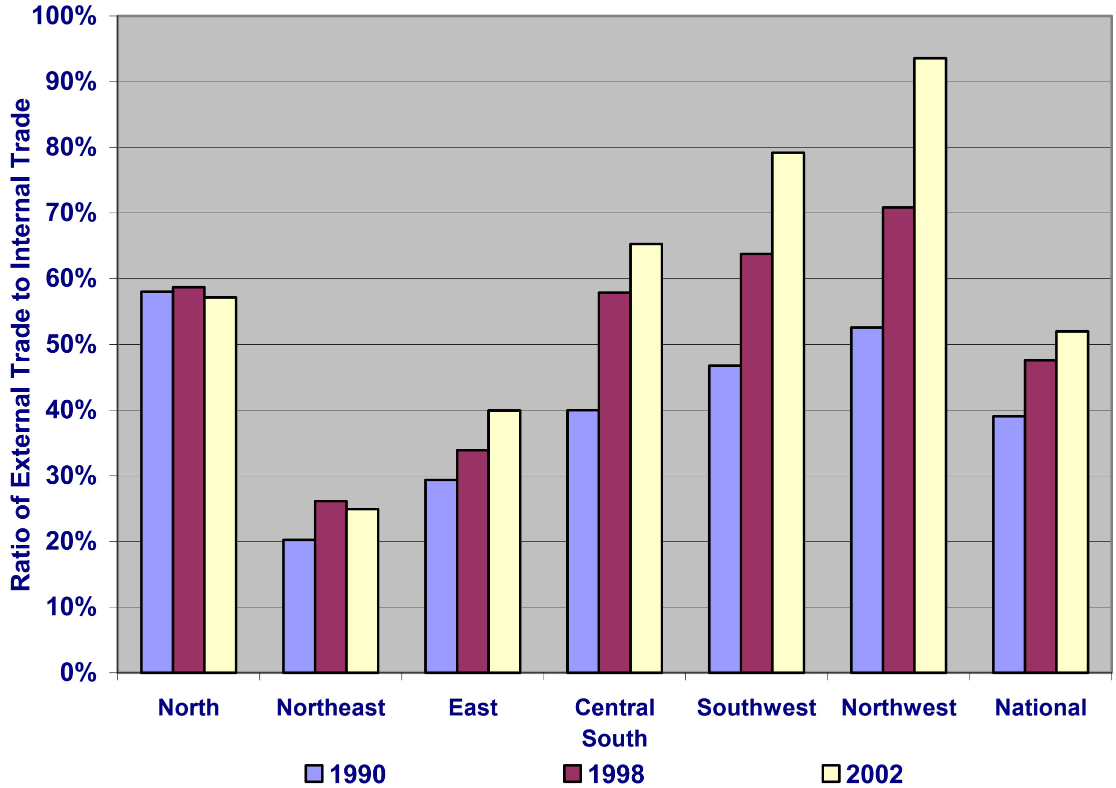
[36] China Transportation Association (2003), page 587.

Figure 19 Regional Modal Shares of Domestic Freight Traffic of China in 2002



Source: China Transportation Association (2003).

Figure 20 Regional Ratios of External to Internal Railway Freight in China, 1990-2002



Source: China Transportation Association (2003). Ratios are calculated from freight data in tonne-km. National figure is the ratio of total interregional freight traffic to total intra-regional freight traffic; it does not reflect international shipments.

Interregional trade in China is growing rapidly, as shown in Figure 20. The ratio of external to internal railway freight trade has been steadily growing not only in the East and Central South regions, but also in the Southwest and Northwest from which they are importing many raw products. The North and Northeast, however, have not seen growth in interregional rail shares.[37]

FACTORS AFFECTING ENERGY USE IN FREIGHT TRANSPORT

Many factors will continue to influence China's energy use in freight transport:

- ***Growing Economy:*** China's government is confident that the rapid economic growth of the last two decades will continue, so that the economy will maintain a 7 percent annual rate of growth in gross domestic product through 2020. A growing economy will mean continued growth in demand for goods and their shipment.
- ***Domestic Freight Transport Modes:*** Railways seem likely to keep dominating long-distance freight traffic in China. Highways seem likely to continue dominating short-distance freight traffic in most regions, as well as medium-distance cargo traffic for products that are perishable. Competition between railways and highways for medium-distance freight movements may have a great impact on energy demand in China since railways are much less energy-intensive. Since interregional trade within China is growing, the role of long-distance freight movements and railways in transport may enlarge, boosting energy efficiency.
- ***International Freight Transport Modes:*** Waterways will keep dominating freight transport in international commerce, which is mostly conducted over the oceans. With continued economic globalisation, ocean cargo volumes will keep growing.
- ***Vehicle Fuel Economy:*** As freight highway traffic continues to expand, oil consumption in China will be increasingly influenced by the fuel efficiency of trucks. Regulatory measures such as gasoline and diesel taxes, fuel economy standards, taxation of inefficient vehicles, and financial incentives to buy efficient vehicles could affect the fuel economy of trucks chosen by shipping companies.

MODAL TRANSPORT SHARES AND ENERGY INTENSITIES IN CHINA

Information on passenger and freight traffic trends, described above, can be combined to arrive at information on overall transport trends and their energy implications in China. To convert passenger traffic volumes from person-km to tonne-km, it is necessary to apply conversion factors that take account of the weight of passengers, their luggage, and the vehicles in which they travel. For this purpose, China's statistical agencies assume that 1 tonne-km of freight traffic is equivalent to 1 person-km of passenger traffic on national railways and waterways, 5 person-km on local railways, 10 person-km on roads and highways, and 11 person-km on airplanes.[38] Applying these conversion factors to the data in Table 11 and Table 15, the overall traffic data in Table 17 can be derived. If the same factors are applied to Table 11 and Table 16, the domestic traffic data in Table 18 result.[39]

As shown in Table 17, overall transport in China quadrupled between 1980 and 2002. Over the same period, the railway share of transport declined by a third (from 54 to 36 percent), the highway share doubled (from 6 to 13 percent), and the waterway share grew substantially (from 39 to 49 percent). However, there are some indications that the mix of transport modes in China may be stabilising. The railway share, which fell an average of 0.86 percentage points yearly in the 1990s,

[37] China Transportation Association (2000), pages 146-183. China Transportation Association (2003), pages 606-7.

[38] Conversion factors from Weihai Statistical Information Network (2004).

[39] Conversion of passenger-km to tonne-km for railways requires distinction between local and national railway traffic. The local railway component is minor; it was 0.3 Bp-km in 1980, 0.3 Bp-km in 1990, 11.8 Bp-km in 2000, and 16.6 Bp-km in 2002. The national railway component was 709.8 Bp-km in 1980, 1,323.3 Bp-km in 1990, 1,810.1 Bp-km in 2000, and 2,035.2 Bp-km in 2002. Data for 2000 and 2002 include joint-venture railways in the local railway category.

fell just 0.25 percentage points per year between 2000 and 2002. The waterway share, which rose 0.79 percentage points yearly in the 1990s, rose just 0.45 percentage points yearly between 2000 and 2002. The highway share, which rose 0.6 percentage points per year in the 1980s, has risen an average of just 0.1 percentage points per year between 1990 and 2002. Waterways now account for nearly half of total traffic in China, railways nearly three-eighths, and highways over one-eighth.

Table 17 Modal Volumes of Total Traffic in China (Billion Tonne-Kilometres)

Year	Railways	Highways	Waterways	Aviation	Pipeline	Total
1980	709.8 (53.9%)	83.7 (6.4%)	518.2 (39.3%)	0.5 (0.0%)	4.9 (0.4%)	1,317.1 (100%)
1985	1,053.9 (49.9%)	207.6 (9.8%)	790.8 (37.4%)	1.5 (0.1%)	60.3 (2.9%)	2,114.0 (100%)
1990	1,323.2 (45.2%)	362.0 (12.4%)	1,175.7 (40.2%)	2.9 (0.1%)	62.7 (2.1%)	2.926.5 (100%)
1995	1,641.3 (41.1%)	515.5 (12.9%)	1772.4 (44.3%)	8.4 (0.2%)	59.0 (1.5%)	3,996.6 (100%)
2000	1,810.1 (36.6%)	679.5 (13.7%)	2,383.5 (48.1%)	13.8 (0.3%)	63.6 (1.3%)	4,950.5 (100%)
2002	2,035.2 (36.1%)	756.3 (13.4%)	2,759.2 (49.0%)	16.6 (0.3%)	68.3 (1.2%)	5,635.6 (100%)

Source: China Transportation Association (2003). Weihai Statistical Information Network (2004).

If only domestic transport is considered, as in Table 18, railways still play a dominant but gradually declining role, while the increase in highway share is more pronounced and the waterway share has been quite steady. Railways now account for nearly three-fifths (59 percent) of domestic traffic, while highways (22 percent) and waterways (17 percent) account for about one-fifth each.

Table 18 Domestic Traffic Volumes in China by Mode (Billion Tonne-Kilometres)

Year	Railways	Highways	Waterways	Aviation	Pipeline	Total
1980	709.8 (73.6%)	83.7 (8.7%)	165.0 (17.1%)	0.5 (0.0%)	4.9 (0.5%)	963.9 (100%)
1985	1,053.9 (66.7%)	207.6 (13.1%)	257.9 (16.3%)	1.5 (0.1%)	60.3 (3.8%)	1,581.1 (100%)
1990	1,323.2 (62.6%)	362.0 (17.1%)	361.6 (17.1%)	2.9 (0.1%)	62.7 (3.0%)	2.112.5 (100%)
1995	1641.3 (58.2%)	515.5 (18.3%)	594.4 (21.1%)	8.4 (0.3%)	59.0 (2.1%)	2,818.6 (100%)
2000	1,810.1 (55.8%)	679.5 (21.0%)	676.2 (20.9%)	13.8 (0.4%)	63.6 (2.0%)	3,243.2 (100%)
2002	2,035.2 (58.8%)	756.3 (21.8%)	585.9 (16.9%)	16.6 (0.5%)	68.3 (2.0%)	3,462.3 (100%)

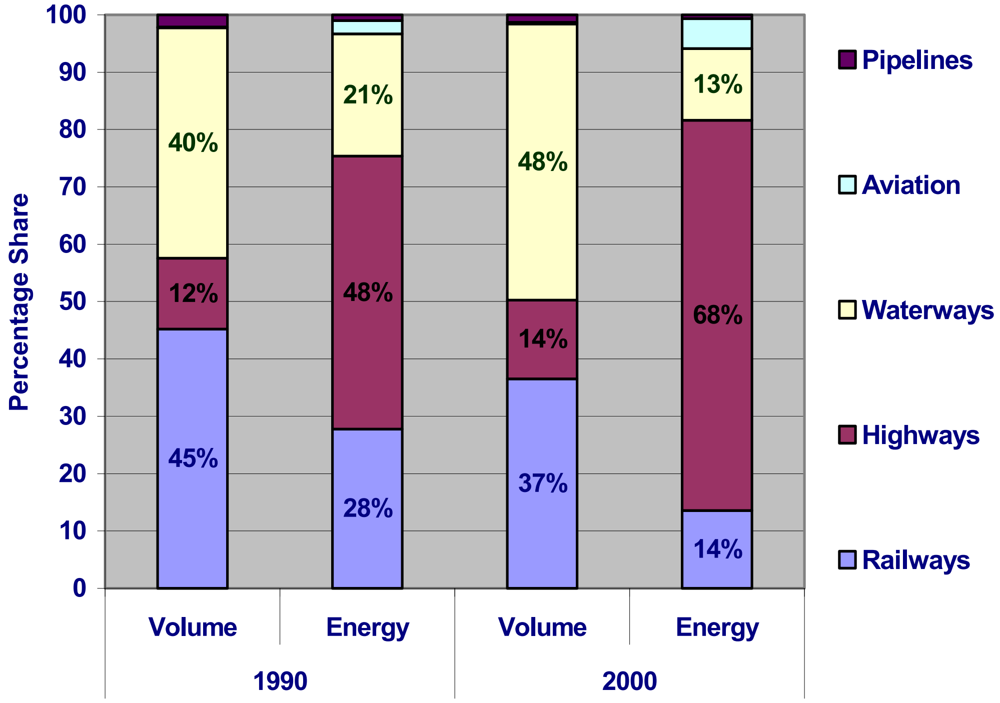
Source: China Transportation Association (2003). Weihai Statistical Information Network (2004).

The contributions of each mode to the volume of traffic and energy consumption 1990 and 2000 are compared in Figure 21. Railways' share of transport sector energy use declined by more than half in just one decade, from about 28 percent to less than 14 percent, though their share of transport volume declined by only about one-fifth. Waterways' share of transport sector energy use also dropped sharply, by about two fifths, from 21 percent to 13 percent, even though their share in the volume of transport grew by one-fifth, from 40 percent to 48 percent. Perhaps most importantly, highways, which accounted for less than half of energy use in transport in 1990 (48 percent), grew to account for over two-thirds of energy use in transport by 2000 (68 percent), even though they still account for less than one-seventh of overall transport volume. [40]

Different transport modes have much different energy intensities, as measured by energy use per unit traffic volume, shown in Table 19. The numerator, energy use for transport (in thousand tonnes oil equivalent), is taken from Table 10. The denominator, total traffic volume (in billion tonne-kilometres), is taken from Table 17. After aviation, highway transport has the greatest energy intensity. Since the share of highway transport has grown, the average energy intensity of transportation has increased even though the energy intensity of most transport modes has declined.

[40] CERS (2002), page 67.

Figure 21 Modal Shares of Transport Volume and Energy Use in China, 1990-2000



Source: CERS (2002). Both passenger and freight traffic are included in this chart.

Table 19 Energy Intensity of Different Transport Modes in China, 1990-2000 (Tonnes Oil Equivalent per Million Tonne-Kilometres)

Transport Mode:	1990	2000	Change
Railways	11.2 toe/Mt-km	7.2 toe/Mt-km	- 36 percent
Highways	70.4 toe/Mt-km	96.4 toe/Mt-km	+ 37 percent
Waterways	9.7 toe/Mt-km	5.0 toe/Mt-km	- 52 percent
Civil aviation	422.3 toe/Mt-km	369.8 toe/Mt-km	- 12 percent
Pipelines	8.8 toe/Mt-km	9.5 toe/Mt-km	+ 8 percent
Average	18.3 toe/Mt-km	19.4 toe/Mt-km	+ 6 percent

Source: APERC analysis of data from CERS (2002) and Chinese Transportation Association (2003).

As the table shows, the energy intensity of highway transport in China increased by more than a third during the 1990s. Thus, China is experiencing not only rapid growth in highway traffic and the number of cars and trucks, but also very substantial growth in the amount of energy required on highways to move a given amount of goods or a given number of people a given distance. This may be due to a variety of factors associated with an increasingly prosperous populace: greater use of air conditioned buses, shifts from buses to private cars and taxis, and reduced fuel efficiency of automobiles caught in urban traffic jams as the number of cars and taxis grows. It is also possible that trucks are being used less efficiently, in energy terms, for freight commerce, as customers demand prompter shipments and merchandise more often travels in trucks that are not fully loaded.

In terms of overall energy use, increasing highway energy intensity is partially compensated by declining energy intensity on railways and waterways. But these other transport modes are less reliant than highway transport on oil, so they compensate much less in terms of oil imports. If current trends continue, China's use of petroleum products for transport will keep growing rapidly, meaning a sustained rise in oil demand and imports and sustained pressure on world oil markets.

TRANSPORTATION AND OIL IMPORTS IN CHINA

INTRODUCTION

It seems inevitable that transport energy demand in China will continue to be boosted by growing incomes and expanding infrastructure, at least for the foreseeable future. This chapter attempts to assess how growth in China's transport needs will affect China's oil demand over the next twenty years. It first describes how the trends discussed in the previous chapter are related to the mix of oil products used in the Chinese economy. It then examines a wide range of scenarios on how growing transport demand may affect China's oil demand and imports over the longer term.

TRANSPORT AND CHINA'S PETROLEUM PRODUCT MIX

TYPES OF FUEL USED IN DIFFERENT TRANSPORT MODES IN CHINA

Petroleum is by far the dominant fuel for transport in China, accounting for 88 percent of total transport energy consumption in 1998.[41] However, different types of transport use different petroleum products. Gasoline is the dominant fuel for cars, minibuses, and small trucks and vans. Diesel is an important fuel for large trucks and buses, as well as ships and railway locomotives. Fuel oil is the dominant petroleum product for shipping, while jet fuel predominates in aviation. Liquefied petroleum gas buses and taxis are promoted by some cities as a clean energy measure.

Other fossil fuels play relatively minor roles in China's transport system. Coal was once the main fuel for railway steam locomotives, but its direct share of energy use in transport is declining. On the other hand, electricity's role in transport is slowly growing, and coal is the main fuel from which electricity is generated. Coal-fired steam locomotives are gradually being replaced by electric locomotives in railway transport. Electrified railways, which extended just 1,700 km and accounted for 3 percent of railways in service in 1980, had grown to 16,900 km and a 24 percent share of railways in service by 2001.[42] Electricity is also used in the subway systems which more and more large cities are building, as well as a few electric vehicle demonstration projects. Compressed natural gas, meanwhile, fuelled 69,300 buses from 270 CNG refilling stations as of March 2003.[43]

GASOLINE

More than 90 percent of gasoline in China is used by motorcycles and automobiles, which include cars, minibuses and light-duty trucks. Between 1996 and 2000, as shown in Table 20, the number of automobiles grew about 40 percent from 8.77 million to 12.25 million, while the number of motorcycles more than doubled from 16.10 million to 37.72 million. The automobile share of gasoline demand declined from 85 percent to 78 percent, while the motorcycle share doubled from 7 percent to 14 percent. Gasoline consumption per motorcycle remained flat at around 0.13 tonnes per year, so total gasoline consumption by motorcycles grew at about the same pace as the number of motorcycles, about 24 percent per year. But gasoline consumption per automobile declined 6.6 percent per year, from 2.85 tonnes in 1996 to 2.17 tonnes in 2000. Hence, while the number of automobiles increased by 8.7 percent per year, total gasoline consumption by automobiles increased just 1.5 percent per year. The declining gasoline intensity of automobiles can probably be attributed to the increased market penetration of private cars, which are relatively light, with a declining share of automobiles comprised of small buses and trucks, which are relatively heavy.[44]

[41] Academy of Macroeconomic Research (2002).

[42] National Bureau of Statistics (2002), page 534.

[43] International Association for Natural Gas Vehicles (2004).

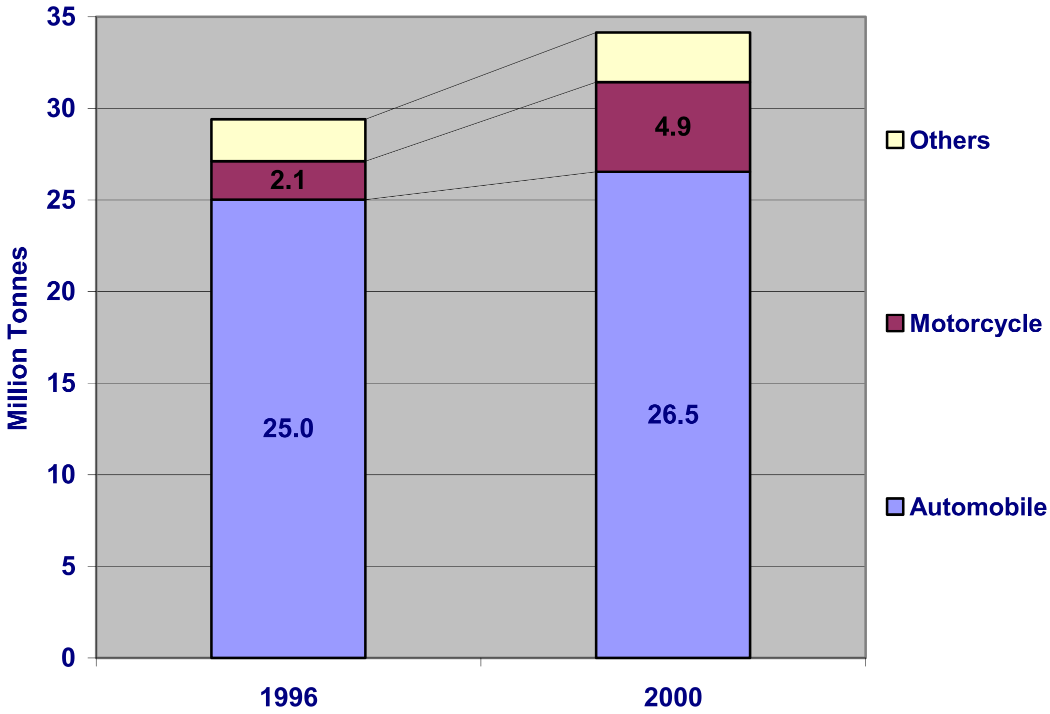
[44] Li and others (2003).

Table 20 Gasoline Consumption by Automobiles and Motorcycles in China, 1996-2000

Indicator	1996	2000	Change
Gasoline Consumption (million tonnes)	29.41	34.15	3.8% per year
Gasoline Consumption by Automobiles	25.02	26.54	1.5% per year
Gasoline Consumption by Motorcycles	2.09	4.90	24.0% per year
Automobile Population (million)	8.77	12.25	8.7% per year
Motorcycle Population (million)	16.10	37.72	23.7% per year
Gasoline Consumed per Automobile (tonnes)	2.85	2.17	- 6.6 % per year
Gasoline Consumed per Motorcycle (tonnes)	0.13	0.13	0.0 % per year

Source: Li and others (2003).

Figure 22 Gasoline Consumption Shares in China, 1996-2000



Source: Li and others (2003).

DIESEL FUEL

Roughly half the diesel fuel in China is consumed by road and farm vehicles, as the transport share of total diesel consumption grew from 34 percent in 1996 to 43 percent in 2000. Between 1996 and 2000, as shown in Table 21, the number of road diesel vehicles grew 73 percent from 2.23 million to 3.85 million, while the number of farm diesel vehicles grew 85 percent from 1.00 million to 1.85 million. The road vehicle share of diesel demand grew from 16 percent to 21 percent, while the farm vehicle share grew from 18 percent to 22 percent. Diesel consumption per road vehicle was a flat 3.68 tonnes per annum, so total diesel consumption by road vehicles grew at the same pace as the number of diesel road vehicles, 14.6 percent per annum. But diesel consumption per farm vehicle automobile declined 3.4 percent annually, from 9.28 tonnes in 1996 to 8.08 tonnes in 2000. Hence, while the number of diesel farm vehicles grew 16.0 percent annually, total diesel consumption by farm vehicles grew somewhat more slowly at 12.6 percent per year. The declining diesel intensity of farm vehicles could be due to increased rural use of cars for passenger transport and light trucks for freight transport, with less off-farm transport performed by large tractors.[45]

[45] Li and Others (2003), pages 16-21.

Unlike gasoline, diesel has a broad range of uses outside the transportation sector, so the factors that influence diesel consumption are more complex. In the power sector, diesel is used for on-site electricity generation when power is unavailable from the grid. The diesel shortage that occurred in some regions in November of 2003 was caused by a power shortage at the time. In recent years, however, the transport sector has been driving overall growth in China's diesel use.[46]

The government used to maintain diesel fuel prices at a low level to help support China's agricultural sector and guarantee adequate food supplies. But controlled diesel prices contributed to sizeable diesel deficits for many years, perhaps in part by reducing incentives for construction of new refining capacity. China struggled with these deficits by importing large amounts of diesel from abroad and requiring an enhanced ratio of diesel to gasoline output at domestic oil refineries. Diesel price controls were eased in 1998, and increased refining capacity brought supplies into better balance, allowing China to export modest amounts of diesel fuel since 1999.[47]

Table 21 Diesel Consumption by Road and Farm Vehicles in China, 1996-2000

Indicator	1996	2000	Change
Diesel Fuel Consumption (million tonnes)	51.44	67.38	9.9 % per year
Diesel Consumption by Road Vehicles	8.21	14.15	14.6 % per year
Diesel Consumption by Farm Vehicles	9.28	14.94	12.6 % per year
Diesel Road Vehicle Population (million)	2.23	3.85	14.6 % per year
Diesel Farm Vehicle Population (million)	1.00	1.85	16.0 % per year
Diesel Consumed per Road Vehicle (tonnes)	3.68	3.68	0.0 % per year
Diesel Consumed per Farm Vehicle (tonnes)	9.28	8.08	- 3.4 % per year

Source: Li and others (2003).

KEROSENE (JET FUEL)

Jet fuel (kerosene) consumption for transport in China grew 16-fold from 0.314 million tonnes in 1980 to 5.056 million tonnes in 1999, while its consumption for other purposes fell 5 percent.[48] Not surprisingly, jet fuel demand is mainly driven by aviation traffic. Domestic output is not sufficient to meet demand growth due to a very low kerosene yield ratio of 3 to 4 percent in domestic refineries. By comparison, the kerosene yield rate in Japan reached 12 percent in 2002.[49] Hence, China has been a net importer of kerosene since 1992, and its kerosene imports reached 1.1 million tons in 1999 or over one-fifth of total kerosene demand. Dependency on kerosene imports is likely to grow with demand for aviation transport. However, this trend may be mitigated by improved domestic kerosene yield ratios as new refineries are built and old ones modernised.[50]

FUEL OIL

Transportation accounts for very little fuel oil use in China, as shown in Table 22. Electric power production and fertiliser production each consume about a quarter of China's fuel oil. By contrast, waterways consume just 5 percent and railways just 1 percent. In the power sector, fuel oil use stems from the period from 1966 through 1973, when oil-fired power plants were built following the successful development of three large new oil fields, as well as from the early 1990s, when some regions built small-scale on-site oil-fired plants to cope with power shortages. During years of high oil prices, when oil-fired plants faced losses, some switched to run on other fuels such as a mixture of water and coal, while others stopped operating. Construction of new oil-fired power plants is not planned, so growth in fuel oil demand from the power sector is not anticipated.[51]

[46] Li and others (2003), pages 16-21.

[47] Deng (2004).

[48] NBS, China Energy Statistical Yearbook (various editions).

[49] JPCE (2003).

[50] NBS, China Energy Statistical Yearbook (various editions).

[51] CEC (2000).

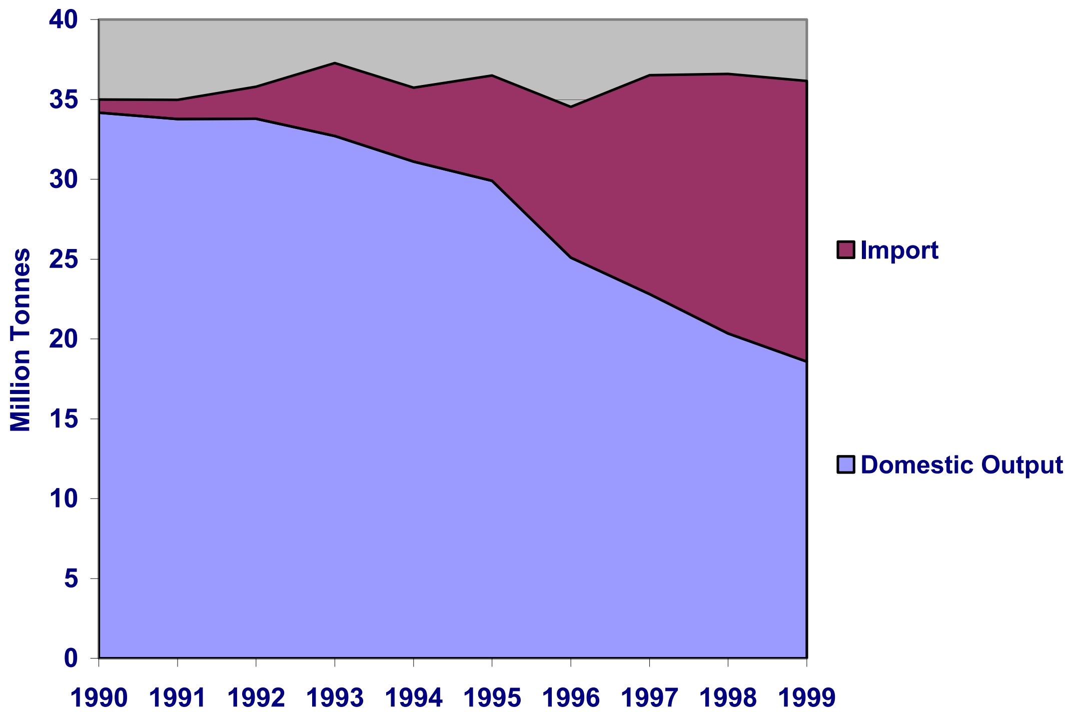
Table 22 Sectoral Fuel Oil Uses and Shares in China, 1999

Consuming Sector	Fuel Oil Share	Fuel Oil Uses
Electric Power	27 percent	Ignition, Generation
Fertilizer, Chemicals	25 percent	Feedstock, Fuel
Building Materials, Glass	17 percent	Fuel
Smelting Industry	16 percent	Fuel
Waterways	5 percent	Fuel
Railways	1 percent	Fuel
Town Gas	2 percent	Fuel
Other	7 percent	Various

Source: CEC (2000).

Since the 1990s, China's government has adopted a policy of substituting coal for fuel oil in boilers and limiting fuel oil consumption to 35 million to 37 million tonnes per annum.[52] As shown in Figure 23, domestic fuel oil output declined from 34.0 million tonnes in 1990 to 18.6 million tons in 1999. The growing gap between fuel oil consumption and production has been met by increasing imports. Russia, Korea and Singapore are China's main fuel oil import suppliers. In 2000, 54 percent of imported fuel oil came from Korea, 20 percent from Russia and 13 percent from Singapore. China relied on imports for nearly half of its fuel oil (46 percent) in 2002.[53] To reduce fuel oil import dependency, the Chinese government supports technology development and demonstration to replace fuel oil ignition at coal-fired power plants with plasma ignition technology and other automotive control technologies. Also, because of fuel oil's high sulphur content, the government is encouraging its replacement in non-transport applications by natural gas.[54]

Figure 23 Fuel Oil Consumption, Production and Imports in China, 1990-1999



Source: CEC (2000).

[52] SETC (2001).

[53] Tian (2003).

[54] SETC (2001).

LPG AND OTHER REFINERY PRODUCTS

Transport accounts for just a small portion of liquefied petroleum gas (LPG) consumption in China. Most of the economy's LPG is consumed by industry as feedstock and by the building sector, where booming consumption has caused LPG imports to grow faster than oil product imports. Other refinery products include naphtha, lubricant, grease, petroleum coke, and asphalt. These products are used for non-transport and non-energy purposes. As shown in Table 23, China has net exports of naphtha and grease and net imports of asphalt, lubricant, and petroleum coke.

Table 23 Imports and Exports of Other Refinery Products in China, 2001-2002

Product (Thousand Tonnes)	2001			2002		
	Import	Export	Net Export	Import	Export	Net Export
Naphtha	109.4	902.4	793.0	242.6	911.1	668.5
Lubricant	680.3	76.9	- 603.4	824.3	66.3	- 758.0
Grease	20.7	543.7	523.0	19.6	623.4	603.8
Petroleum Coke	209.0	1,602.8	1,393.8	1,277.7	779.1	- 498.6
Asphalt	1,630.7	160.1	- 1,470.6	2,273.9	102.7	- 2,171.2

Source: Tian (2003).

TRANSPORT FUELS AND THE OIL REFINERY PRODUCT MIX

In order to assess the possible impact of expanding transportation fuel needs on China's oil product mix and import requirements, it is useful to map the flow of oil products from upstream production to downstream refining and use, as shown in Figure 24:

- Starting on the left side of the flow chart, data on production and imports can be combined to arrive at total crude oil requirements of 232,490 kilotonnes.[55]
- Netting out 0.4 percent in transport losses, 0.5 percent in direct use of crude oil for power generation and heating, and 4.8 percent for oil stockpiles and inventories, 94.3 percent of crude oil supply or 219,320 kt proceeds to refineries.[56]
- Of the crude that goes to refineries, 9.0 percent is used in energy consumption or is otherwise lost, 35.0 percent yields diesel fuel, 19.7 percent yields gasoline, 3.7 percent yields kerosene or jet fuel, 8.6 percent yields fuel oil, 5.4 percent yields liquefied petroleum gas, and 18.6 percent yields other petroleum products.[57]
- Oil product imports are added to refinery production outputs to arrive at the down-stream supply of each product; there were no net imports of diesel or gasoline.[58]
- The downstream supply of each product is allocated to various end-use sectors. It may be noted that the transport sector takes up 57.6 percent of diesel, 85.8 percent of gasoline, 61.0 percent of kerosene and jet fuel, and 6.0 percent of fuel oil.[59]

---

[55] Production figures from IPE (2003). Import figures from Tian (2003). Total crude sums production and imports.

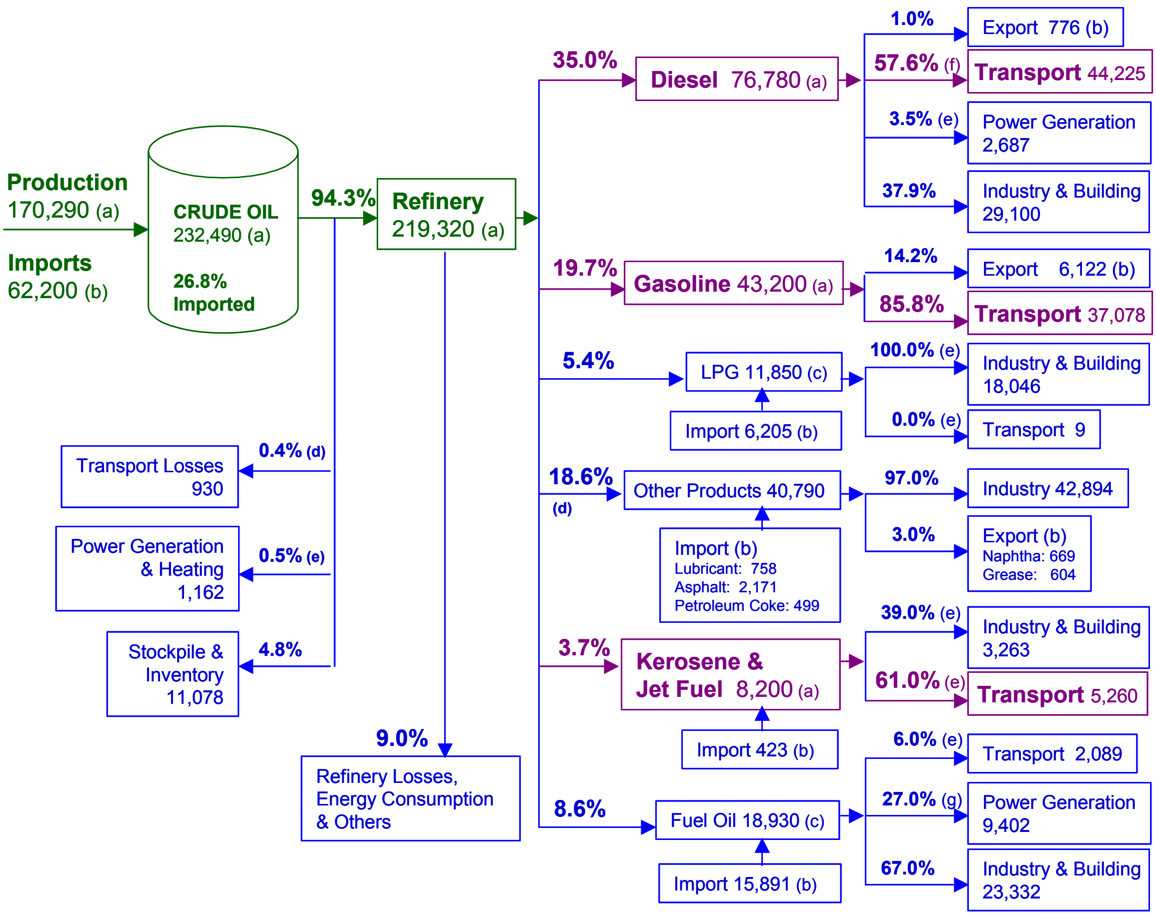
[56] Crude supply and refinery data in IPE (2003) show 94.3% of crude proceeds to refineries, meaning 5.7% does not. Sinopec (2001) indicates transport losses of 0.4% while NBS (2001) indicates power generating and heating uses of 0.5%, leaving 4.8% for stockpiles and inventories.

[57] Yield ratios for most fuels were calculated by dividing data on specific fuel yields by total refinery input. Data on diesel, gasoline and kerosene and jet fuel yields from IPE (2003). Data on fuel oil and LPG yields from 3E (2002) and (2003). Yield ratio for other petroleum products directly from Sinopec (2001). Refinery losses were calculated as a residual.

[58] Import data for each fuel from Tian (2003).

[59] Allocations of product supplies to exports from Tian (2003). For gasoline, transport supply is total supply less exports. For diesel supply, transport data from Li and others (2003), power data from NBS (2001), industry and building figures calculated as a residual. For kerosene and jet fuel, as well as LPG, end-use shares from NBS (2001). For fuel oil end use, transport share from NBS (2001), power share from CEC (2000), industry and buildings share calculated as a residual. For other products, all domestic use is by industry, to which supply is calculated as total supply less exports.

Figure 24 Oil Refinery Product Flows in China, 2002 (Thousand Tonnes)



Sources: (a) IPE (2003). (b) Tian (2003). (c) 3E (2002), (2003). (d) Sinopec (2002). (e) NBS (2001). (f) Li *et. al.* (2003). (g) CEC (2000).

Some observations can be delivered from this analysis:

- China depends on imports for 26.8 percent of its crude oil supply and for 31.7 percent of its overall supply of oil products. Modest exports of gasoline and diesel fuel are outweighed by imports of LPG, fuel oil, jet fuel and other oil products.[60]
- Oil consumption for transport accounts for 36.4 percent of total oil consumption.[61]
- China's refineries are highly oriented toward production of diesel fuel. The ratio of diesel to gasoline in refinery volumes was 1.77 to 1 in 2002. In most other economies, the ratio is reversed, with more production of gasoline than diesel.[62]

[60] Total oil import dependency is calculated by adding net energy-related oil product imports, in tonnes oil equivalent, to crude imports, and dividing the sum by total crude and oil product supply. Conversion factors in toe per tonne of product are assumed to be 1.02 for diesel, 1.03 for gasoline, 1.20 for LPG, 1.03 for jet fuel, and 1.00 for fuel oil. Then imports are -792 ktoe for diesel, -6,306 ktoe for gasoline, 7,446 ktoe for LPG, 436 ktoe for jet fuel, and 15,891 ktoe for fuel oil. Oil product imports thus total 16,676 ktoe, which added to 62,200 ktoe crude imports gives 78,876 ktoe total imports. Adding oil product imports of 16,676 ktoe to crude supply of 232,490 ktoe gives total oil supply of 249,166 ktoe Dividing 78,876 ktoe total imports by 249,166 ktoe total oil supply gives oil import dependency of 31.7 percent.

[61] Conversion factors in toe per tonne of product are assumed to be 1.02 for diesel, 1.03 for gasoline, 1.20 for LPG, 1.03 for jet fuel, and 1.00 for fuel oil. Then transport consumption is 45,110 ktoe for diesel, 38,190 ktoe for gasoline, 11 ktoe for LPG, 5,418 ktoe for jet fuel, and 2,089 ktoe for fuel oil. Transport consumption thus totals 90,817 ktoe, which is 36.4 percent of total consumption of 249,166 ktoe as calculated in the preceding footnote.

[62] For example, JPCE (2003) cites a gasoline to diesel production ratio of 1.47 to 1 for Japanese refiners in 2002. This is equivalent to a 0.68 to 1 ratio of diesel to gasoline, which is well under half the contemporaneous ratio in China.

- Because of a national policy that pushes refineries to increase the yield ratio of light-head fuels such as diesel and gasoline, refineries do not produce enough fuel oil to meet domestic needs, and nearly half of the economy's fuel oil must be imported.
- At present, China exports substantial amounts of gasoline, equal to 14.2 percent of refinery output in 2002. This is due to the fact that the 15.3 percent gasoline share of oil product use is less than the 19.7 percent gasoline share of refinery runs.[63]

SCENARIOS OF TRANSPORTATION ENERGY DEMAND IN CHINA

FUTURE TRANSPORT DEMAND AND ENERGY CONSUMPTION

While China's demand for transport and transport fuels will clearly continue to grow along with its economy, considerable uncertainty surrounds the long-run rate of economic growth and how expanding output will translate into expanding needs for transport. The elasticity of transport demand with respect to GDP has fluctuated over the last two decades, as shown in Table 24. It averaged around 0.9 in the 1980s and 0.5 in the 1990s, or around 0.7 from 1980 through 2002. GDP growth has averaged 9 or 10 percent over the period, but the Sixteenth National Congress set a target of four-fold growth between 2000 and 2020, implying growth of 7 percent per annum.[64]

Table 24 GDP Elasticities of Transport in China, 1980-2002

Time Period	Annual GDP Growth	Annual Growth in Transport Volume			GDP Elasticity of Transport		
		Passenger	Freight	Total	Passenger	Freight	Total
1980-1985	10.8 %	14.2 %	8.8 %	9.9 %	1.32	0.82	0.92
1985-1990	7.7 %	4.9 %	7.4 %	6.7 %	0.64	0.96	0.88
1990-1995	12.1 %	9.8 %	6.4 %	6.4 %	0.82	0.53	0.53
1995-2000	8.2 %	6.4 %	4.4 %	4.4 %	0.77	0.53	0.53
2000-2002	7.7 %	7.3 %	6.9 %	6.7 %	0.95	0.89	0.86
1980-2002	**9.5 %**	**8.6 %**	**6.7 %**	**6.8 %**	**0.91**	**0.71**	**0.72**

Sources: APERC calculations. GDP data from National Bureau of Statistics (2003a).

It seems reasonable to postulate that over the period through 2020 on average, the elasticity of demand for transport in China will be somewhere in the range experienced over the period from 1980 to present. Also, in view of the significant decline in elasticity from the 1980s to the 1990s, the lower end of the range would seem more likely than the upper end. While the elasticity has spiked upward in the more recent period from 2000 through 2002, that period saw an aggressive programme of infrastructure expansion that is not apt to be maintained at quite so torrid a pace. Thus, the projections presented below assume a mid-case transport demand elasticity for China of 0.7, with lower case variants of 0.6 and 0.5 and less likely upper case variants of 0.8 and 0.9.

To estimate future energy demand from transport, it is necessary to consider not only the relationship of transport demand to GDP but also the relationship of energy demand to transport demand. As shown in Table 19 above, the energy intensity of transport demand rose from 18.3 tonnes oil equivalent per million tonne-kilometres in 1990 to 19.4 toe per Mt-km in 2000. If intensity continued to increase along these lines, it would reach 20.5 toe per Mt-km by 2010 and 21.6 toe per Mt-km by 2020. On the other hand, various policy options may be available to moderate the increased energy intensity, through either improved fuel efficiency (especially in automobiles) or modal shifts (such as from highway to water or rail). For purposes of illustration,

[63] Dividing 38,190 toe gasoline consumption by 249,165 ktoe total consumption gives a 15.3 percent consumption share.

[64] Jiang (2002). Elasticities are calculated from passenger, freight and total transport volumes in earlier tables, as well as GDP figures in National Bureau of Statistics (2003a). In billion 1995 US dollars, GDP was 164.5 in 1980, 274.1 in 1985, 396.4 in 1990, 700.2 in 1995, 1,040.3 in 2000 and 1,207.7 in 2002. Passenger transport elasticities here are calculated directly from data in passenger-km to give a more direct picture than data converted to tonne-km, as the conversion factors are approximate. The total transport elasticities can only be calculated from data in tonne-km, whatever their inaccuracy, but distortion is minimized by the fact that passenger transport is still a small share of overall transport.

the projections presented here assume intensity in 2020 is somewhere between the recent level of 2000 (19.4 toe per Mt-km) and the straight-line projection of recent trends (21.6 toe per Mt-km).

Table 25 China's Transport Energy Demand in 2020 as a Function of Assumptions about Transportation Demand Elasticity and Transport Energy Intensity, Assuming that GDP Growth Averages 7 Percent Annually from 2000

Energy Intensity	Percentage Change in Transport Demand per Percentage Change in GDP				
of Transport	0.5	0.6	0.7	0.8	0.9
21.6 toe per Mt-km	213 Mtoe	243 Mtoe	278 Mtoe	318 Mtoe	363 Mtoe
20.5 toe per Mt-km	202 Mtoe	231 Mtoe	264 Mtoe	302 Mtoe	344 Mtoe
19.4 toe per Mt-km	191 Mtoe	219 Mtoe	250 Mtoe	286 Mtoe	326 Mtoe

Source: APERC calculations.

If the elasticity of transport demand and the energy intensity of transport are in the ranges just described, then China's transport energy demand in 2020 could range from 191 Mtoe to 363 Mtoe, with a mid-case estimate of around 264 Mtoe, as shown in Table 25.[65] By comparison, APERC has previously estimated 2020 transport energy demand of 205 Mtoe[66], Guo at Tsinghua University has estimated 246 Mtoe,[67] and the Academy of Macroeconomic Research has projected 279 Mtoe.[68] These other estimates, as can be seen, fall mostly in the lower half of the indicated range.

Table 26 Transport Fuel Shares Projected by Academy of Macroeconomic Research

	Projected Transport Fuel Amounts		Projected Transport Fuel Shares	
Transport Fuel	1998	2020	1998	2020
Gasoline	35.00 Mtoe	112.68 Mtoe	44.2 %	40.4 %
Diesel	30.42 Mtoe	100.27 Mtoe	38.4 %	35.9 %
Jet Fuel	3.97 Mtoe	49.72 Mtoe	5.0 %	17.8 %
Electricity	2.19 Mtoe	8.35 Mtoe	2.8 %	3.0 %
Gas	0.26 Mtoe	6.91 Mtoe	0.3 %	2.5 %
Other Oil	0.39 Mtoe	0.80 Mtoe	0.5 %	0.3 %
Coal	6.99 Mtoe	0.33 Mtoe	8.8 %	0.1 %
Total	79.22 Mtoe	279.06 Mtoe	100.0 %	100.0 %

Source: Academy of Macroeconomic Research (2002).

The study by China's Academy of Macroeconomic Research helpfully projects how the shares of different transport fuels in transport energy demand may evolve. In this view, the shares of gasoline and diesel decline, while the share of jet fuel increases, as shown in Table 26. These same projected fuel shares can be applied to other projections of transport energy demand.

FUTURE TRANSPORT DEMAND AND OIL PRODUCT CONSUMPTION

It is interesting to consider how growing demand for transport may affect the mix of oil products consumed in China. In all likelihood, the bulk of changes in overall oil product demand will be determined by changes in the transport sector. The electricity sector is also growing rapidly, but very little if any new generating capacity is likely to be fuelled by oil. Rather, the bulk of new generating capacity is projected to come from coal-fired, hydro, and nuclear powerplants. While some new coal-fired plants may continue to use fuel oil for ignition purposes, alternative ignition

[65] The projections in the table start with a base total traffic demand of 4,950 Bt-km in 2000, which grows through 2020 at an annual rate equal to the elasticity times the 7 percent assumed GDP growth rate. The projected 2020 traffic demand in Bt-km is then multiplied by the energy intensity in toe per Mt-km to arrive at 2020 energy demand in thousand toe.

[66] APERC (2002b), pages 35-36.

[67] Guo (2003), pages 45-46.

[68] Zhou, D. (2003), pages 639-651.

technologies now being demonstrated are likely case to become less costly. While the industrial sector's demand for fuel oil might grow, it is plausible to assume that most growth of industrial energy use will come in the form of electricity. Thus, it makes sense to assess what may happen to the oil product mix if oil product demand grows in the transport sector but does not grow in other sectors.

Table 27 applies the product shares for gasoline, diesel and jet fuel cited in Table 26 to the low, medium and high scenarios of transport energy demand shown in Table 25. Together, these three key fuels are assumed to account for 94.13 percent of transport fuel demand in 2020:

- Gasoline demand would grow by some 40 million tonnes in the low case, 70 Mt in the mid case and 109 Mt in the high case from 2002 levels of about 37 Mt.
- Diesel demand would grow by some 24 million tonnes in the low case, 51 Mt in the mid case, and 86 Mt in the high case from 2002 levels of about 44 Mt.
- Jet fuel demand would grow by some 29 million tonnes in the low case, 42 Mt in the mid case, and 59 Mt in the high case from 2002 levels of about 5 Mt.

Table 27 Growth in Demand for Key Transport Fuels in China through 2020

Transport Fuel	Demand for Major Transport Fuels in 2020				Change in Transport Fuel Demand from 2002			
	Share	Low Case	Mid Case	High Case	2002 Base	Low Case	Mid Case	High Case
Gasoline	40.4 %	77.1 Mt	106.6 Mt	146.6 Mt	37.1 Mt	40.0 Mt	69.5 Mt	109.5 Mt
Diesel	35.9 %	68.6 Mt	94.9 Mt	130.4 Mt	44.2 Mt	24.4 Mt	50.6 Mt	86.2 Mt
Jet Fuel	17.8 %	34.0 Mt	47.0 Mt	64.7 Mt	5.3 Mt	28.8 Mt	41.8 Mt	59.4 Mt
Total	100.0 %	191.0 Mt	264.0 Mt	363.0 Mt	88.7 Mt	93.2 Mt	161.9 Mt	255.1 Mt

Source: APERC calculations.

Table 28 shows the impact of growing transport fuel demand on oil product shares. The change in transport fuel demand from 2002, shown on the right side of Table 27, is added to the 2002 oil product demand to calculate oil product demand in 2020, on the left side of Table 28. The projected product demands are shown as shares of product demand on the right side of the table:

- Gasoline's share of oil product demand could grow from 19 percent in 2002 to between 26 percent and 32 percent in 2020.
- Diesel's share of oil product demand, which was 34 percent in 2002, seems likely to remain steady at between 32 percent and 34 percent in 2020.
- Jet fuel's share of oil product demand could grow from less than 4 percent in 2002 to between 12 percent and 14 percent by 2020.

Table 28 Effect of Growing Transport Fuel Demand on China's Oil Product Shares

Petroleum Product	Demand for Petroleum Products in China				Shares of Petroleum Product Demand			
	2002	Low 2020	Mid 2020	High 2020	2002	Low 2020	Mid 2020	High 2020
Gasoline	43.2 Mt	83.2 Mt	112.7 Mt	152.7 Mt	19.1 %	26.1 %	29.1 %	31.8 %
Diesel	76.8 Mt	101.2 Mt	127.4 Mt	163.0 Mt	34.0 %	31.7 %	32.9 %	33.9 %
Jet Fuel	8.6 Mt	37.4 Mt	50.4 Mt	68.0 Mt	3.8 %	11.7 %	13.0 %	14.2 %
Fuel Oil	34.8 Mt	34.8 Mt	34.8 Mt	34.8 Mt	15.4 %	10.9 %	9.0 %	7.2 %
LPG	18.0 Mt	18.0 Mt	18.0 Mt	18.0 Mt	8.0 %	5.7 %	4.7 %	3.7 %
Other	44.2 Mt	44.2 Mt	44.2 Mt	44.2 Mt	19.6 %	13.9 %	11.4 %	9.2 %
Total	225.7 Mt	318.9 Mt	387.6 Mt	480.8 Mt	100.0 %	100.0 %	100.0 %	100.0 %

Source: APERC calculations.

FUTURE TRANSPORT DEMAND AND OIL IMPORTS

For several reasons, it seems likely that a significant portion of China's incremental transport fuel needs will be imported directly as refined products rather than being refined within China:

- China's gasoline and jet fuel product needs are poised to grow very substantially.
- The economy's refinery mix is heavily weighted in favour of such light-head fuels, and increased refining of such fuels could throw the mix into greater imbalance.
- There is evidence that imported oil products are cheaper than domestically-produced oil products, indicating that China's refineries may be at a competitive disadvantage.[69]

Without presupposing the fraction of incremental transport fuel needs that will be imported directly, it may be interesting to examine the implications of alternative scenarios in which a quarter, half, and three-quarters of incremental transport fuel needs are imported directly as products. The impacts on incremental product and crude imports are shown for the low-, mid- and high-case scenarios of transport growth in Table 29, Table 30 and Table 31. The incremental needs for each fuel through 2020, shown in the third column of each table, are taken from Table 27. Calculated crude import needs take account of 9.0 percent refinery uses and 5.7 percent other losses. The tables indicate that even if just a quarter of China's incremental transport fuel needs are imported directly as products, annual product imports could grow by 10 to 27 Mt for gasoline, by 6 to 22 Mt for diesel, and by 7 to 15 Mt for jet fuel. If half the economy's fuel needs are imported, imports could grow 20 to 55 Mt for gasoline, 12 to 43 Mt for diesel, and 14 to 30 Mt for jet fuel.

Table 29 Low Transport Growth Case Impacts on China's Product and Crude Imports

Petroleum Product	Net 2002 Imports	Incremental 2020 Needs	25% as Product Import		50% as Product Import		75% as Product Import	
			Product Imp	Crude Imp	Product Imp	Crude Imp	Product Imp	Crude Imp
Gasoline	-6.1 Mt	40.0 Mt	10.0 Mt	35.0 Mt	20.0 Mt	23.3 Mt	30.0 Mt	11.7 Mt
Diesel	-0.8 Mt	24.4 Mt	6.1 Mt	21.3 Mt	12.2 Mt	14.2 Mt	18.3 Mt	7.1 Mt
Jet Fuel	0.4 Mt	28.8 Mt	7.2 Mt	25.1 Mt	14.4 Mt	16.7 Mt	21.6 Mt	8.4 Mt
Total	-6.5 Mt	93.2 Mt	23.3 Mt	81.4 Mt	46.6 Mt	54.2 Mt	69.9 Mt	27.1 Mt

Table 30 Mid Transport Growth Case Impacts on China's Product and Crude Imports

Petroleum Product	Net 2002 Imports	Incremental 2020 Needs	25% as Product Import		50% as Product Import		75% as Product Import	
			Product Imp	Crude Imp	Product Imp	Crude Imp	Product Imp	Crude Imp
Gasoline	-6.1 Mt	69.5 Mt	17.4 Mt	60.7 Mt	34.8 Mt	40.5 Mt	52.1 Mt	20.2 Mt
Diesel	-0.8 Mt	50.6 Mt	12.7 Mt	44.2 Mt	25.3 Mt	29.5 Mt	38.0 Mt	14.7 Mt
Jet Fuel	0.4 Mt	41.8 Mt	10.4 Mt	36.5 Mt	20.9 Mt	24.3 Mt	31.3 Mt	12.2 Mt
Total	-6.5 Mt	161.9 Mt	40.5 Mt	141.4 Mt	81.0 Mt	94.2 Mt	121.4 Mt	47.1 Mt

Table 31 High Transport Growth Case Impacts on China's Product and Crude Imports

Petroleum Product	Net 2002 Imports	Incremental 2020 Needs	25% as Product Import		50% as Product Import		75% as Product Import	
			Product Imp	Crude Imp	Product Imp	Crude Imp	Product Imp	Crude Imp
Gasoline	-6.1 Mt	109.5 Mt	27.4 Mt	95.6 Mt	54.7 Mt	63.7 Mt	82.1 Mt	31.9 Mt
Diesel	-0.8 Mt	86.2 Mt	21.6 Mt	75.3 Mt	43.1 Mt	50.2 Mt	64.7 Mt	25.1 Mt
Jet Fuel	0.4 Mt	59.4 Mt	14.9 Mt	51.9 Mt	29.7 Mt	34.6 Mt	44.6 Mt	17.3 Mt
Total	-6.5 Mt	255.1 Mt	63.8 Mt	222.7 Mt	127.6 Mt	148.5 Mt	191.3 Mt	74.2 Mt

[69] Zhang (2004) reports unit refinery process costs 10 percent higher in China than elsewhere in the Asia Pacific region, with unit refinery energy use one-third higher than in advanced plants and the average refinery processing 2.06 Mton per year as compared with 55 Mton for the world on average. Dai (2002) reports refinery process costs in China are double world levels. Yu (2002) reports refinery process costs of $26 per tonne, more than triple world levels of $7.20.

Different scenarios of transport energy use have different implications for China's oil import dependency. Meanwhile, different assumptions about the share of crude and product imports for the incremental oil demand that stems from growing transport needs will affect the overall mix of crude and product imports. The results of different assumptions are shown in Table 32, Table 33 and Table 34 assuming that crude production in China remains at 2002 levels of 170 billion tonnes.[70]

Table 32 Low Transport Growth Case Impacts on China's Oil Import Reliance and Mix

2020 Oil Supply Indicators: Low Case Assumptions For Transport Growth	Indicator Values by Share of Incremental Transport Fuel Imported as Product					
	25% as Product Import		50% as Product Import		75% as Product Import	
	Amount	Share	Amount	Share	Amount	Share
(a) Total Crude Oil Demand	313.9 Mt	88.4 %	286.7 Mt	81.7 %	259.6 Mt	74.8 %
(b) Less: Total Crude Oil Production	170.3 Mt	48.0 %	170.3 Mt	48.5 %	170.3 Mt	49.0 %
(c) Equals: Total Crude Oil Imports	143.6 Mt	40.4 %	116.4 Mt	33.2 %	89.3 Mt	25.7 %
(d) Plus: Total Oil Product Imports	48.1 Mt	11.6 %	64.4 Mt	18.3 %	87.7 Mt	25.2 %
(e) Equals: Total Oil Imports	184.7 Mt	52.0 %	180.8 Mt	51.5 %	177.0 Mt	51.0 %
(f) Total Oil Demand (b + e)	354.9 Mt	100.0 %	351.1 Mt	100.0 %	347.3 Mt	100.0 %

Table 33 Mid Transport Growth Case Impacts on China's Oil Import Reliance and Mix

2020 Oil Supply Indicators: Mid Case Assumptions For Transport Growth	Indicator Values by Share of Incremental Transport Fuel Imported as Product					
	25% as Product Import		50% as Product Import		75% as Product Import	
	Amount	Share	Amount	Share	Amount	Share
(a) Total Crude Oil Demand	373.8 Mt	86.5 %	326.7 Mt	76.8 %	279.6 Mt	66.8 %
(b) Less: Total Crude Oil Production	170.3 Mt	39.4 %	170.3 Mt	40.0 %	170.3 Mt	40.7 %
(c) Equals: Total Crude Oil Imports	203.6 Mt	47.1 %	156.4 Mt	36.8 %	109.3 Mt	26.1 %
(d) Plus: Total Oil Product Imports	58.3 Mt	13.5 %	98.7 Mt	23.2 %	139.2 Mt	33.2 %
(e) Equals: Total Oil Imports	261.8 Mt	60.6 %	255.2 Mt	60.0 %	248.5 Mt	59.3 %
(f) Total Oil Demand (b + e)	432.1 Mt	100.0 %	425.5 Mt	100.0 %	418.8 Mt	100.0 %

Table 34 High Transport Growth Case Impacts on China's Oil Import Reliance and Mix

2020 Oil Supply Indicators: High Case Assumptions For Transport Growth	Indicator Values by Share of Incremental Transport Fuel Imported as Product					
	25% as Product Import		50% as Product Import		75% as Product Import	
	Amount	Share	Amount	Share	Amount	Share
(a) Total Crude Oil Demand	455.2 Mt	84.8 %	381.0 Mt	72.4 %	306.7 Mt	59.5 %
(b) Less: Total Crude Oil Production	170.3 Mt	31.7 %	170.3 Mt	32.4 %	170.3 Mt	33.0 %
(c) Equals: Total Crude Oil Imports	284.9 Mt	53.1 %	210.7 Mt	40.0 %	136.4 Mt	26.4 %
(d) Plus: Total Oil Product Imports	81.6 Mt	15.2 %	145.3 Mt	27.6 %	209.1 Mt	40.5 %
(e) Equals: Total Oil Imports	366.5 Mt	68.3 %	356.0 Mt	67.6 %	345.5 Mt	67.0 %
(f) Total Oil Demand (b + e)	536.7 Mt	100.0 %	526.3 Mt	100.0 %	515.8 Mt	100.0 %

[70] Total crude demand (a) in these tables is the sum of incremental crude demand (from the previous three tables) and 2002 baseline crude demand (which may be derived from the oil product flow chart presented earlier). Baseline crude demand for each fuel is calculated as the refinery output of that fuel divided by a refinery use factor of approximately 0.91 and an other loss factor of approximately 0.943. Thus, the baseline crude draw is 50.281 Mt for gasoline, 89.365 Mt for diesel, 9.544 Mt for jet fuel, 22.033 Mt for fuel oil, 13.792 Mt for LPG, and 47.476 Mt for other oil products, or a total of 232.490 Mt. Total product imports (d) in these tables are the sum of incremental product demand (from the previous three tables) and 2002 baseline net product imports (from the previous three tables or the oil product flow chart). Baseline net product imports are –6.122 Mt for gasoline, -0.776 Mt for diesel, 0.423 Mt for jet fuel, 15.891 Mt for fuel oil, 6.205 Mt for LPG, and 2.155 Mt for other oil products, or a total of 17.776 Mt.

The assumption that oil production in China will be flat is naturally key to the conclusion that oil import dependency will rise. The assumption of flat oil production is based on official estimates and recent trends. Crude output of China's refineries grew about 1.7 percent annually from 138 Mt in 1990 to 169 Mt in 2002.[71] However, most major oilfields in central and eastern China have entered a stable or declining period of production. Experts estimate that crude output could peak around 170 Mt to 200 Mt in 2010 and then decline to around 170 Mt again by 2020.[72]

If the assumption of flat domestic oil production holds true, several observations may be made:

- China's overall oil import dependency, around 32 percent in 2002, could grow by 2020 to around 52 percent as a result of low-case increases in transport fuel demand, 60 percent in case of moderate transport fuel demand growth, and 68 percent in the event that transport fuel demand grows at the upper end of the projected range. If China's oil consumption were also to increase outside the transport sector, the overall oil import dependency of the economy could grow even larger.[73]
- The wide range of plausible oil import dependency scenarios, which are based on different assumptions about the relationship of transport demand to GDP growth and the energy intensity of transport demand, can be taken to indicate that the level of dependency may be significantly influenced by policies to limit growth in transport demand (such as better city planning) and to improve the energy efficiency of key transport modes (such as through automobile fuel efficiency standards).
- Direct importation of oil products, as opposed to importation and refining of crude, is likely to account for 12 to 15 percent of China's total oil demand by 2020 if a quarter of the incremental transport-related fuel demand is met through direct product imports, 18 to 28 percent of total oil demand if half of the transport increment is met through direct product imports, and 25 to 41 percent of total oil demand if three-quarters of the transport increment is met through direct imports.
- The huge potential increases in China's oil product imports may offer significant opportunities to other APEC economies that have spare oil refining capacity in the short run or can build new refining capacity economically in the long run.
- China's total crude oil demand would grow by 2020 to a range of 314 to 455 Mt if a quarter of incremental transport fuel demand is met through direct product imports (an increase of 35 to 96 percent from the 2002 level of 232 Mt), 287 to 381 Mt if half of the transport increment is met through direct product imports (an increase of 23 to 64 percent), and 260 to 307 Mt even if three-quarters of the transport increment is met through direct imports (an increase of 12 to 32 percent).
- The growth in China's crude oil demand implies a huge need for refining capacity. Assuming that refining capacity requires investment of roughly US$160 per tonne,[74] then even if no existing capacity were retired and required replacement (which is highly unlikely), China's refinery investment needs through 2020 would be on the order of $13 billion to $36 billion if a quarter of the growth in transport fuel demand were met by direct product imports, $9 billion to $24 billion if half the growth in transport fuel use were met through product imports, and $4 billion to $12 billion if three-quarters of the growth in transport fuel use were met through product imports.

---

[71] NBS (2003a), page 136.

[72] Liu (2002).

[73] Ito (2004) estimates that with low, medium, or high GDP growth of 5.6, 7.2 or 8.3 percent annually, China's oil import dependency in 2020 would reach 68, 75 or 80 percent, assuming 146 Mt of domestic oil production in that year. With annual domestic oil production of 170 Mt as assumed here, the dependency figures would be 63, 71 and 77 percent.

[74] IEA (2003a) cites the capital cost of a new refinery in a non-OECD country at around $8,000 per barrel of capacity per day. Using the conversion factor in IEEJ (2003), page 321, this would be roughly $160 per tonne of capacity per year.

CHINA'S OIL SECURITY AND TRANSPORTATION POLICY

INTRODUCTION

As described above, China's demand for oil is poised to grow substantially over the next two decades, along with growth in transport. This will mean a major increase in China's oil import bill and will tend to raise world oil prices. Hence, measures to limit growth of oil use and enhance the security of oil supply should benefit not only China but also the rest of the world. Such measures may include diversification of supply sources, creation of oil supply stockpiles, petroleum product imports, urban road traffic policies and transportation systems, and improved vehicle fuel economy. This chapter briefly evaluates the growing cost of China's oil imports and options for limiting them.

THE COST OF GROWING OIL IMPORTS FOR CHINA AND THE WORLD

To get a sense of what growing transport fuel needs may cost the Chinese economy, the incremental fuel needs estimated in the preceding chapter can be multiplied by projected oil prices. As shown in Table 35, the Energy Information Administration in the United States projects a 2020 world oil price equivalent to $190 per tonne in its most recent reference case, $124 per tonne in its low-case scenario and $253 per tonne in its high-case scenario. Other recent price projections by the International Energy Agency and DRI/WEFA are very close to those in EIA's reference case.[75]

Table 35 Some Recent Projections of World Crude Oil Price in 2020

Projection (Year Made)	2020 Oil Price	Equivalent Price
EIA Reference Case (2004)	$26.02 per barrel	$190 per tonne
EIA Low Case (2004)	$16.98 per barrel	$124 per tonne
EIA High Case (2004)	$34.63 per barrel	$253 per tonne
WEFA Reference (2002)	$25.39 per barrel	$185 per tonne
IEA Reference Case (2002)	$25.56 per barrel	$187 per tonne

Sources: EIA (2004a), figures in 2002 dollars. WEFA (2002). IEA (2002b). Equivalent prices assume 7.3 barrels per tonne.

The impact of growing transport fuel needs on China's yearly bill for oil imports by 2020 is illustrated in Table 36. If all incremental demand for gasoline, diesel and jet fuel were met by refining crude oil, China's import bill could increase by $13 billion to $27 billion with low growth in transport energy use, by $23 billion to $48 billion with moderate growth in transport energy use, and by $37 billion to $75 billion with high growth in transport energy use. If a portion of transport needs were met by importing oil products, the import bill would be higher due to product markups.

Table 36 Illustrative Oil Import Bill for China in 2020 as a Function of Projected Oil Price and Transport Growth Scenario if All Incremental Demand is Crude

Transport Growth Scenario	Low Case Oil Price	Reference Oil Price	High Case Oil Price
Low Transport Growth Case	$13 billion	$21 billion	$27 billion
Mid Transport Growth Case	$23 billion	$36 billion	$48 billion
High Transport Growth Case	$37 billion	$56 billion	$75 billion

A rough assessment can be made of how China's incremental oil demand might affect world oil prices. Modeling estimates are available of future oil price and supply over various five- and ten-year intervals. From these, it is possible to derive implied elasticities of supply, which is to say the percentage change in supply that is elicited by a one percent change in price. These are not "true"

[75] EIA (2004a), page 191. Global Insight Incorporated (2002). IEA (2002b), page 96.

elasticities since they do not measure the supply response to price at a fixed time, but they still serve as reasonable proxies for what the true elasticities might be. From Table 37, it can be seen that the inverse of the implied elasticity, or percentage change in price per percentage change in supply, is about 1/3 for EIA, about 2/3 for DRI/WEFA, and about 1 for IEA and (on average) PIRA.

Table 37 Implied Supply Elasticities of World Oil Price in Recent Studies

Projection	Year	Oil Price	Oil Supply	Price Change	Supply Change	Elasticity	1/ Elasticity
EIA (a)	2005	$23.27	80.7 Mbpd				
	2010	$23.99	89.3 Mbpd	3.1 %	10.7 %	3.44	0.29
	2015	$24.72	98.4 Mbpd	3.0 %	10.2 %	3.35	0.30
	2020	$25.48	107.8 Mbpd	3.1 %	9.6 %	3.11	0.32
	2025	$26.57	118.3 Mbpd	4.3 %	9.7 %	2.28	0.44
WEFA (b)	2005	$20.80	83.2 Mbpd				
	2010	$21.70	89.1 Mbpd	4.3 %	7.1 %	1.64	0.61
	2015	$23.76	102.6 Mbpd	9.5 %	15.2 %	1.60	0.63
	2020	$25.39	112.7 Mbpd	6.9 %	9.8 %	1.43	0.70
IEA (c)	2010	$21.47	88.9 Mbpd				
	2020	$25.56	104.1 Mbpd	19.0 %	17.1 %	0.90	1.11
PIRA (d)	2005	$22.43	82.4 Mbpd				
	2010	$23.33	91.5 Mbpd	4.0 %	11.0 %	2.75	0.36
	2015	$26.32	99.5 Mbpd	12.8 %	8.7 %	0.68	1.47

Sources: EIA (2003), figures in 2001 dollars. Global Insight Incorporated (2002). IEA (2002b). PIRA (2002).

With these elasticities in hand, the impact of China's incremental transport-related oil demand (ITROD) on the world oil price in 2020 may now be roughly approximated as follows:

- As shown in Table 38, China's ITROD represents 1.9 to 2.1 percent of the world oil supply projected for 2020 with slow transport growth, 3.3 to 3.6 percent with moderate transport growth, and 5.3 to 5.7 percent with rapid transport growth.
- Applying supply elasticities between 1 and 3, China's ITROD would correspond to a price change of 0.6 to 2.1 percent with slow transport growth, 1.1 to 3.6 percent with moderate transport growth, and 1.8 to 5.7 percent with rapid transport growth.
- At EIA's reference price of $26.02 per barrel, such percentage changes would affect the 2020 world oil price per barrel by $0.16 to $0.55 with slow growth, $0.29 to $0.94 with moderate growth, and $0.47 to $1.48 with rapid growth in transport.
- At EIA's low-case price of $16.98 per barrel, such percentage changes would affect the 2020 world oil price per barrel by $0.10 to $0.36 with slow growth, $0.19 to $0.61 with moderate growth, and $0.31 to $0.97 with rapid growth in transport.
- At EIA's high-case price of $34.63 per barrel, such percentage changes would affect the 2020 world oil price per barrel by $0.21 to $0.73 with slow growth, $0.38 to $1.25 with moderate growth, and $0.62 to $1.97 with rapid growth in transport.

Table 38 China's Transport Oil Demand Growth As Share of 2020 World Oil Supply

	Incremental Transport Oil Demand			2020 World Oil Supply		Supply Share	
Transport Growth Scenario	Product	Crude Mtoe	Crude Mbpd	IEA	WEFA	IEA	WEFA
Low Transport Growth Case	93.2 Mt	108.5 Mtoe	2.17 Mbpd	104.1 Mtoe	112.7 Mtoe	2.1%	1.9%
Mid Transport Growth Case	161.9 Mt	188.5 Mtoe	3.77 Mbpd	104.1 Mtoe	112.7 Mtoe	3.6%	3.3%
High Transport Growth Case	255.1 Mt	296.9 Mtoe	5.94 Mbpd	104.1 Mtoe	112.7 Mtoe	5.7%	5.3%

Sources: EIA (2004a). Global Insight Incorporated (2002). IEA (2002b).

ENHANCING OIL SECURITY BY DIVERSIFYING SOURCES OF SUPPLY

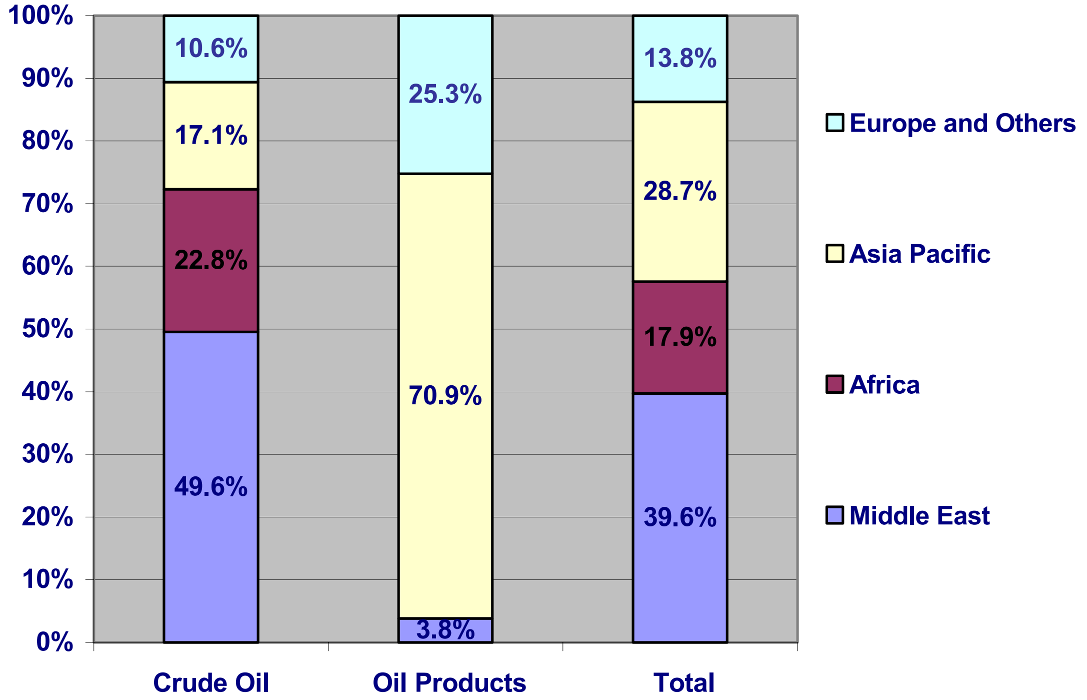
China's sources of external oil supply in 2002 are shown in Table 39 and Figure 25. Of its crude oil imports, nearly half come from the Middle East and nearly a quarter come from Africa., so nearly three-quarters in all were shipped through the Straits of Malacca. Of its oil product imports, however, over two-thirds came from elsewhere in the Asia Pacific region. Direct importation of oil products therefore represents less of a risk than crude oil imports in terms of shipping lane safety. It has also allowed China to strengthen its economic ties with other APEC economies.

Table 39 Sources of China's Crude Oil and Oil Product Imports in 2002

Product	Middle East	Africa	Asia Pacific	Europe/Other	Total
Gasoline	0 Mt	0 Mt	0 Mt	0 Mt	0 Mt
Diesel	0 Mt	0 Mt	0.450 Mt	0.031 Mt	0.481 Mt
Jet Fuel	0.230 Mt	0 Mt	1.703 Mt	0 Mt	1.932 Mt
Fuel Oil	0.496 Mt	0 Mt	11.308 Mt	4.783 Mt	16.588 Mt
Crude Oil	34.392 Mt	15.797 Mt	11.850 Mt	7.369 Mt	69.408 Mt
Total Oil	35.025 Mt	15.797 Mt	25.370 Mt	12.184 Mt	88.476 Mt

Source: China Petroleum and Petrochemical Industry Economics Research (2003). To calculate total oil in Mtoe, assumes 1 tonne of crude or fuel oil equals 1 toe, 1 tonne of diesel equals 1.02 toe, and 1 tonne of gasoline or jet fuel equals 1.03 toe.

Figure 25 Regional Shares of China's Oil Imports in 2002



Source: China Petroleum and Petrochemical Industry Economics Research (2003).

To assess the regional concentration of China's oil imports, a Herfindahl index may be used. While such an index is typically used to assess the degree to which markets are dominated by a few firms, it can also reveal whether markets are dominated by a particular region. The Herfindahl index measures the degree of market monopoly as the sum the squares of market shares:

$$H = \sum_i X_i^2 \quad \text{where } X_i \text{ is the market share of the } i^{\text{th}} \text{ supplier}$$

In a typical product market, the value of H can theoretically range from 1 for a perfect monopoly, with just one firm, to zero, for perfect competition, with an infinite number of firms, each with an infinitesimal share of the market. Here, since we are evaluating the split of China's product imports between just four regions, the lowest possible value for H would be 0.25, with each region providing 1/4 of the imports, so that the square of each region's share is 1/16.

As shown in Table 40, the concentration of China's crude oil imports among the four regions being considered has fluctuated quite a bit over the last several years, with the Herfindahl score declining sharply in 1999, increasing again in 2000 and 2001, and dropping once more in 2002. While there have apparently been efforts to diversify sources of crude away from the Middle East, the regional concentration of China's crude imports has not shown a definitive downward trend. On the other hand, it can be observed that the overall concentration is less when oil products are added into the mix; with oil products in the mix, the score would drop from 0.338 to 0.291 in 2002. This implies that the importation of oil products can improve China's oil security to some degree.

Table 40 The Regional Concentration of China's Crude Oil Imports, 1998-2002

Year	Middle East	Africa	Asia Pacific	Europe/Other	Total
1998	16.37 Mt (59.9%)	2.19 Mt (8.0%)	5.47 Mt (20.0%)	3.00 Mt (11.0%)	27.32 Mt (H=0.418)
1999	16.90 Mt (46.2%)	7.25 Mt (19.8%)	6.83 Mt (18.7%)	5.63 Mt (15.4%)	36.61 Mt (H=0.311)
2000	37.65 Mt (53.6%)	16.95 Mt (24.1%)	10.61 Mt (15.1%)	5.05 Mt (7.2%)	70.27 Mt (H=0.373)
2001	33.86 Mt (56.2%)	13.55 Mt (22.5%)	8.68 Mt (14.4%)	4.17 Mt (6.9%)	60.26 Mt (H=0.392)
2002	34.39 Mt (49.5%)	15.80 Mt (22.8%)	11.85 Mt (17.1%)	7.37 Mt (10.6%)	69.41 Mt (H=0.338)

Source: China Petroleum and Petrochemical Industry Economics Research (2003).

ENHANCING OIL SECURITY THROUGH OIL SUPPLY STOCKPILES

Since China has become reliant on imports for a major portion of its oil needs, the government decided in 2001 to build up a system of oil stockpiles to shelter the economy from potential oil supply disruptions.[76] The Tenth Five Year Plan for 2001-2005 initially stated that "China plans to build up the national strategic oil stockpile of 8 million cubic metres by 2005." But this specific target, equivalent to 6 Mt, was soon dropped in favour of more ambitious goals. The government now intends to build up a stockpile that can meet the International Energy Agency's standard of being able to replace 90 days of imports in an emergency.[77] The stockpile will be managed by the National Oil Stockpile Office, established in April 2003 under the Energy Bureau of the National Development and Reform Commission. Its management is one of the Energy Bureau's five main responsibilities.[78] The timetable for the oil stockpile's development is currently as follows:

- By 2005, China's oil reserves are to have a storage capacity equal to 35 days of imports, of which 14 days of reserves would be managed directly by the government and 21 days would be managed by state-owned enterprises.
- By 2010, the economy's oil stockpiles should equal 50 days of imports, of which 22 days will be managed by the government and 28 days by public companies.[79]
- By 2020, it is anticipated that the strategic oil supply stockpiles will reach the IEA standard of 90 days, with a total capacity of 40 to 50 million tonnes.[80]

ENHANCING OIL SECURITY THROUGH OIL PRODUCT IMPORTS

China could improve its oil security by changing its oil import strategy to import less crude oil and import more oil products. Such a strategy could prove beneficial in several respects:

[76] IEA (2002c).

[77] China Daily (2001).

[78] APEC Energy Working Group (2003), page 39.

[79] Feng (2004).

[80] Liu (2002).

- ***Supply source diversification:*** Importing more oil products from Europe or Africa could diversify China's oil supply sources. As noted above, China imports oil products mainly from APEC member economies and crude oil mainly from the Middle East. Diversifying supply sources would spread and lower its risks. (For the APEC region as a whole, diversification would not increase, since the economies producing the oil products are also importing crude from the Middle East.)
- ***Reduced refinery investment needs:*** As China's need for oil products grows, it will need to import and refine more crude oil or import products directly. Greater direct product imports would thus avoid some investment in new refinery capacity.
- ***Reduced risk of refinery over-investment:*** If massive investment in new refineries were undertaken in anticipation of growing oil product requirements, there could be a glut of refining capacity in the event that demand growth should stall. But if a major share of new oil product needs were met through direct product imports, a slowdown in demand growth could be met immediately by reducing such imports, without creating a bubble of unneeded refining capacity in the economy.
- ***Use of spare refinery capacity in other APEC economies:*** World oil refinery capacity exceeds world oil consumption. APEC economies like Singapore, Chinese Taipei and Thailand have spare refinery capacity, as shown in Table 41. China can import specific oil products that meet its needs. This will strengthen economic ties with other APEC member economies and promote regional economic development.

Table 41 Oil Consumption and Refinery Capacity in Selected APEC Economies, 2002

Economy	Refinery Capacity	Consumption	Spare Capacity
Australia	0.926 Mbpd	0.846 Mbpd	0.080 Mbpd
China	5.744 Mbpd	5.362 Mbpd	0.382 Mbpd
Indonesia	1.116 Mbpd	1.072 Mbpd	0.044 Mbpd
Japan	4.721 Mbpd	5.337 Mbpd	-0.616 Mbpd
Singapore	1.255 Mbpd	0.699 Mbpd	0.556 Mbpd
South Korea	2.316 Mbpd	2.288 Mbpd	0.028 Mbpd
Chinese Taipei	1.159 Mbpd	0.817 Mbpd	0.342 Mbpd
Thailand	0.983 Mbpd	0.746 Mbpd	0.237 Mbpd
Total	18.220 Mbpd	17.167 Mbpd	1.053 Mbpd

Source: BP (2003).

ENHANCING OIL SECURITY THROUGH URBAN TRANSPORT POLICIES

As large cities face increasing road congestion from growing numbers of automobiles, with associated traffic delays and pollution, some are adopting measures to help limit growth in road traffic. Beijing and Shanghai have both promoted public transportation, and Shanghai has also made a concerted effort to limit the population of private cars. Both approaches can limit growth in oil use by making transport less energy-intensive and less oil-dependent. Buses are less energy-intensive than cars since they carry more passengers per unit of weight. Subways and trolleys are fuelled not by oil, but by electricity, which is mainly generated from plentiful indigenous coal.

Beijing's efforts to develop public transport involve both subways and buses. Beijing's subway system has provided some 2.3 billion person-trips since 1998, accounting for 12 percent of total passenger traffic within the city. Several subway projects are under construction. The length of subway routes was to reach to 114 km by the end of 2003 and is targeted to expand to 300 km by 2008 and 1000 km by 2020. Meanwhile, special lanes reserved for buses are to more than triple to 300 km by 2010, covering three-quarters of the city's major roadways. To encourage switching from cars to public buses, the city is building parking lots at the edge of its most developed areas. Building on this experience, the next five-year plan for China gives priority to public transport, with the goal of increasing its share to 30 percent in large cities and 20 percent in other cities by 2010.[81]

[81] Qiu (2004). Asia Pulse (2004).

Shanghai issues only a limited number of automobile license plates, allocated through an auction. Bid prices at the auction have increased steadily, nearly doubling in just five months from 18,800 yuan in January to 35,000 yuan in May 2003. The cost of obtaining a license plate in Shanghai is therefore much higher than in Beijing and almost 120 times higher than in other large cities around Shanghai, such as Hangzhou in Zhejiang Province and Suzhou in Jiangsu Province. Shanghai also has 44 percent more public transport vehicles than does the economy's capital. At least partly as a result of such differences, as shown in Table 42, Shanghai has just one vehicle for about every seven in Beijing, with only one-tenth the number of vehicles per hundred households. This is true even though Shanghai has a larger population with a higher income per capita, with a better-developed road network and a more dispersed pattern of urban development.[82]

Table 42 Comparison of Transportation Indicators for Shanghai and Beijing

Transportation Indicator	Beijing	Shanghai	Note
Population of Private Vehicles (thousand)	624.1	87.2	Data of 2001
License plate number fee (RMB)	124	35,000	Data of 2003
Population (thousand)	11,223	13,271	
GDP (current RMB, million)	284,565	495,084	
GDP per Capita (current US dollars)	3,063	4,507	1US$ = 8.277 RMB
Urban Population Density (persons per square km)	3,189	1,950	Data of 2001
Paved Road Area per capita (square metres)	8.3	13.6	Data of 2001
Residential Floor Space per Capita (square metres)	25.4	26	Data of 2001
Population of Public Transport Vehicles	12,676	18,245	Data of 2001
Population of Taxis	65,155	46,921	Data of 2001
Private cars per Hundred Households	2.6	0.2	Data of 2001
Disposable income (RMB per person)	11,578	12,883	Data of 2001
Living expenditure (RMB per person)	8,923	9,336	Data of 2001

Sources: Shen (2003). NBS (2002).
Note: Population of private vehicles excludes motorcycles. Public transport vehicles include buses, trolleys and subways.

ENHANCING OIL SECURITY THROUGH IMPROVED FUEL ECONOMY

It should be clear from the preceding discussion that improved vehicle fuel economy could help limit the pace of growth in China's demand for gasoline and diesel fuel. In the mid-case projection shown, which assumes 7 percent annual economic growth, 70 percent elasticity of transport demand with respect to GDP, and a small increase in the energy-intensity of transport, China's oil requirements would increase by 264 Mtoe per annum. If the overall efficiency of transport could be improved by just 10 percent, annual oil requirements would thus grow 26 Mt less. As an ancillary benefit, assuming mid-case oil price projection of $190 per tonne in 2020, such an efficiency improvement would reduce the economy's projected yearly oil import bill by $5 billion. With carbon dioxide emissions of 3.07 tonnes per tonne of oil, carbon dioxide emissions could also be reduced by some 80 Mt per annum as a result of such a 10 percent transport efficiency boost.

It is not yet clear to what extent fuel economy is likely to be improved in China, but the government seems clearly to understand its importance. In March 2003, the former State Economic and Trade Commission informed all automobile manufacturers to submit data on the fuel economy of their vehicles, with a view to establishing fuel economy targets in the Eleventh Five Year Plan for automobile industry development that will extend from 2006 though 2010. In preparation for the establishment of such targets, standardised national test procedures for measuring the fuel consumption of light duty vehicles are in the process of being approved.[83]

[82] Shen (2003). NBS (2002).
[83] State Economic and Trade Commission (2002) and (2003).

TRENDS IN CHINA'S ELECTRIC POWER SECTOR

INTRODUCTION

Over three-quarters of China's electricity is generated from coal, and most analysts project that coal will continue to dominate the economy's electric generating mix for decades to come. But there are major alternatives to conventional coal-fired powerplants, including high-efficiency gas-fired combustion turbines, nuclear power plants, hydropower, wind power, and advanced coal and gas combustion cycles with carbon sequestration. Collectively, such alternative generating options could put a significant dent in coal's share of the Chinese power market over the next fifty years.

Under current conditions, coal-fired power is usually much cheaper than gas-fired power in China since domestic coal is so abundant. But charges are starting to be imposed on emissions of atmospheric pollutants, and if such charges rise significantly, the economic balance could tilt in favour of less polluting natural gas, as well as nuclear and renewable power. Hydropower potential in China is large, and only a small fraction of it has been exploited. China's wind resources are vast, and costs of electricity generation from wind are coming down, so plans for wind power development have substantially expanded. Nuclear power is currently in a slow phase around the world, but the number of nuclear plants in China could well increase sharply. All of these factors may cut into the market share that business-as-usual projections foresee for China coal.

In policy terms, a shift toward less polluting power generation technologies could be seen as the extension of a trend that has long been underway. In displacing much direct use of coal by homes and businesses for heating and industrial processes, coal-fired power plants with scrubbers for removing particulates and sulphur dioxide have already reduced the public health and environmental threats from these pollutants enormously. Further development in the direction of gas-fired plants, carbon-sequestering plants, and nuclear and renewable plants could be seen to further advance public health and environmental objectives set by the Chinese government.

Indeed, the government has ambitious plans for the development of nuclear power and hydro power, as well as for expanding the electric power grid to make the output of distant hydro plants available to urban population centres. Furthermore, the government has persisted in construction of the West-to-East gas pipeline, as well as new gas-fired powerplants to use the pipeline's gas, even though the delivered gas is very costly in comparison to alternatives. Such initiatives have been undertaken in part to improve the air quality in China's eastern cities. In this light, the current structure and likely future direction of China's electric generating mix are detailed below.

CHINA'S ELECTRICITY GENERATING MIX IN 2002

China has the second largest power industry in the world with 379 GW of generating capacity in 2002. As shown in Table 43, about two-thirds of its generating capacity and three-quarters of its generation are fuelled by coal. Most of the economy's remaining electricity comes from hydropower.[84]

China's generating mix is quite different from that in the world as a whole. As shown in Table 43 and Table 44, about three-eighths of the world's electricity is generated from coal, about half the share that is generated from coal in China. Gas and nuclear power each generate about one-sixth of the world's electricity, far more than in China. In both China and the world as a whole, however, hydropower accounts for about one-sixth of the total electricity that is generated.[85]

[84] SETC (2003), page 1. CERS (2002), pages 45-48. Zhang (2002).

[85] International Energy Agency (2002b), pages 411-13.

Table 43 Fuel Shares of Generating Capacity and Output in China in 2002

Powerplant Type	Electric Generating Capacity Amount	Electric Generating Capacity Share	Electricity Generated Amount	Electricity Generated Share
Coal-Fired Power	252.1 GW	66.5%	1,281 TWh	74.4%
Gas or Oil-Fired	12.1 GW	3.2%	61 TWh	3.6%
Large Hydropower	84.6 GW	22.3%	271 TWh	15.7%
Other Renewable	26.0 GW	6.9%	83 TWh	4.8%
Nuclear Power	3.7 GW	1.0%	25 TWh	1.5%
Total	378.5 GW	100.0%	1,721 TWh	100.0%

Sources: SETC (2003), CERS (2002), Zhang (2002). Note: Coal and gas-or-oil amounts assume coal is 95.43% of thermal capacity and output per 2000 fuel consumption statistics in EDMC (2003). For plants 6 MW and larger, actual coal share is 95.57% for capacity and 94.33% for generation. Other renewable generation includes 80 TWh of mini-hydro, nearly 1 TWh of large wind, and 2 TWh of miscellaneous sources such as geothermal, tidal, biogas, and photovoltaic power.

Table 44 Fuel Shares of Generating Capacity and Output in the World in 2000

Powerplant Type	Electric Generating Capacity Amount	Electric Generating Capacity Share	Electricity Generated Amount	Electricity Generated Share
Coal-Fired Power	1,078 GW	30.8%	5,989 TWh	38.9%
Gas-Fired Power	729 GW	20.8%	2,676 TWh	17.4%
Oil-Fired Power	501 GW	14.3%	1,241 TWh	8.1%
Hydropower	776 GW	22.2%	2,650 TWh	17.2%
Other Renewable	61 GW	1.7%	249 TWh	1.6%
Nuclear Power	354 GW	10.1%	2,586 TWh	16.8%
Total	3,498 GW	100.0%	15,391 TWh	100.0%

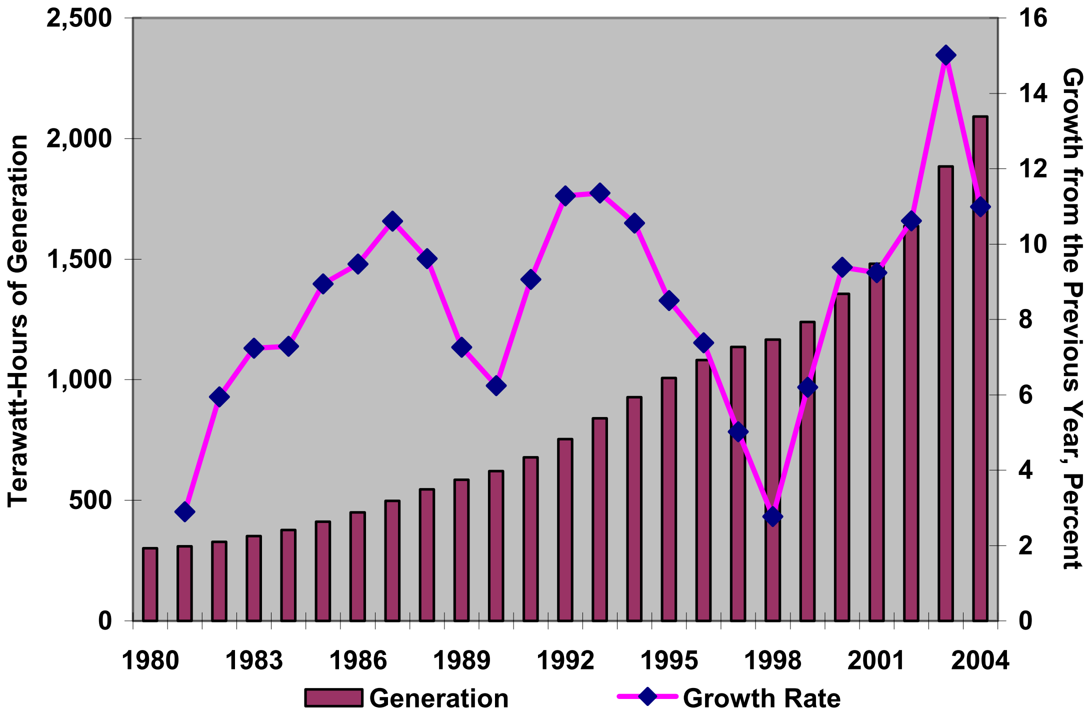
Source: International Energy Agency (2002b)

HISTORICAL GROWTH IN CHINA'S ELECTRICITY SECTOR

China has sometimes suffered from power shortages in the past. To avoid further shortages as the economy grew, China embarked on a major programme of power plant construction in the 1980s which made the power sector the fastest-growing sector within the energy industry. A brief power surplus occurred from 1996 through 1998 due to the closing of some inefficient and energy-intensive state-owned enterprises, as well as the economic fallout of the Asian financial crises. But power was once again in short supply by 2001, and shortages spread to 21 provinces in 2003. So a new round of investment in power plants has begun, in hopes of ending power shortages by 2005.

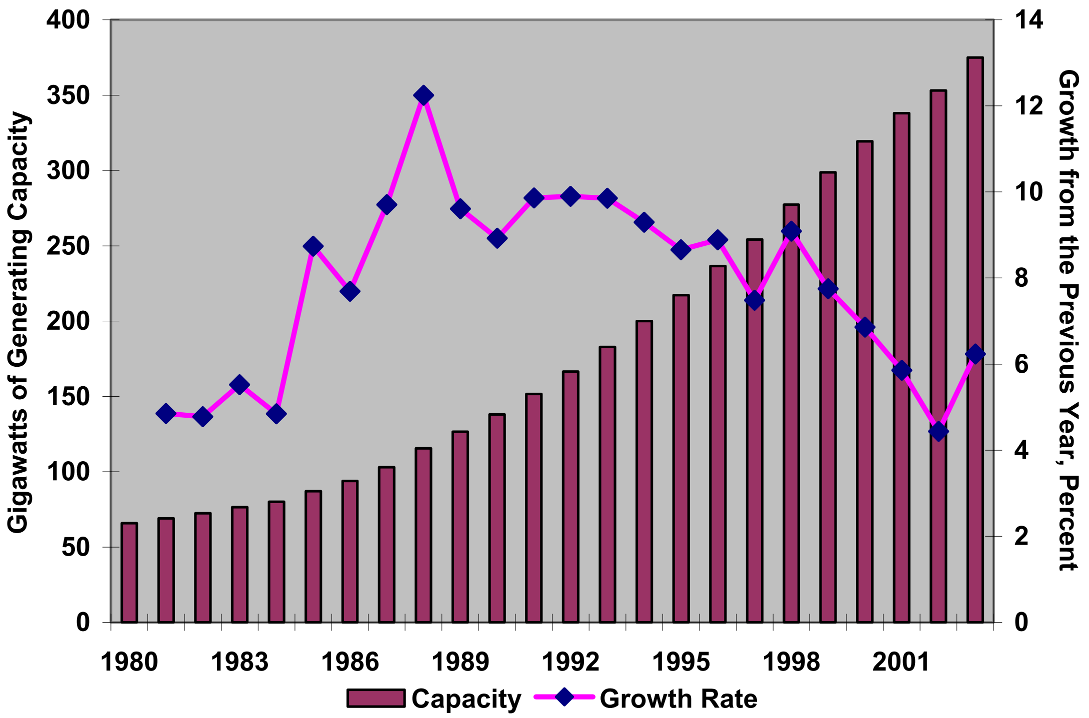
Figure 26 and Figure 27 show how China's electric generation and generating capacity have grown since 1980. Yearly growth has fluctuated widely, from 3 percent to 16 percent for generation and from 4 to 12 percent for generating capacity. For generation, the growth rate slid from over 11 percent 1993 to just 3 percent in 1998 before moving sharply upward again to 15 percent by 2003. For capacity, after more than a decade of rapid growth from 1987 to 1998, with an average increase of 8.1 percent per annum, growth in generating capacity declined markedly from 9.1 percent in 1998 to 4.4 percent in 2002 before moving upward again. Thus, the pattern of growth for capacity apparently lags the pattern of growth for generation by about five years.

Figure 26 Growth of Electricity Generation in China, 1980-2004



Source: National Bureau of Statistics (2003b). Estimates for 2004 and late 2003 from Shi (2003).

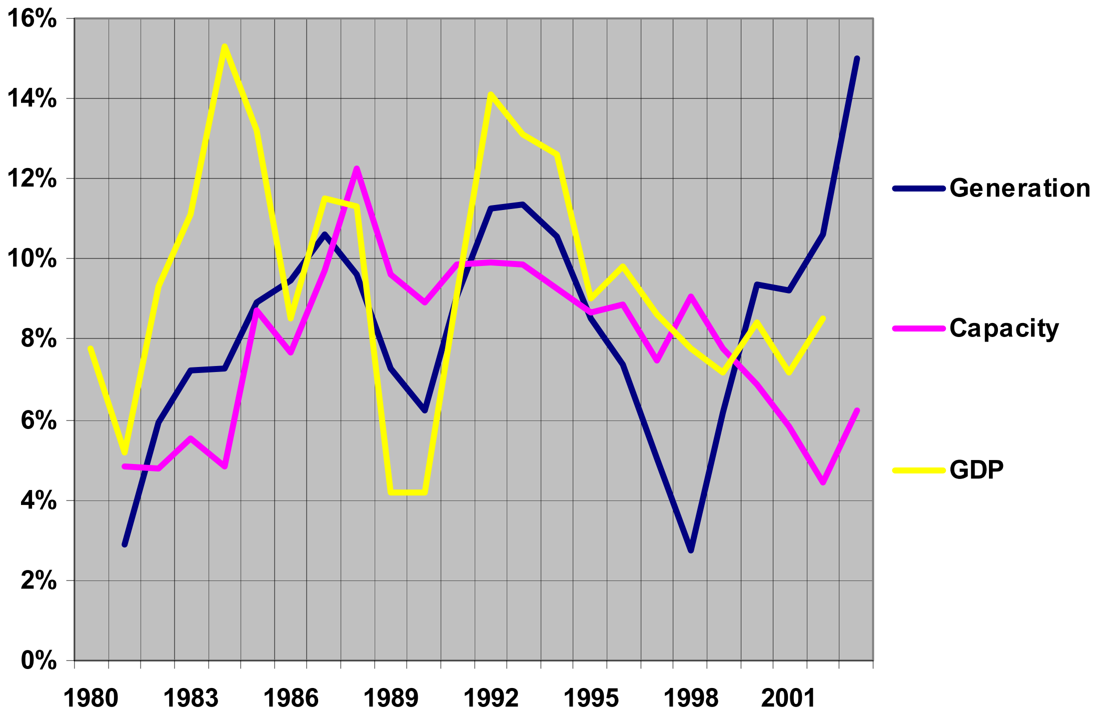
Figure 27 Growth of Installed Electric Generating Capacity in China, 1980-2003



Source: National Bureau of Statistics (2003b). Estimate for late 2003 from Shi (2003).

The reason for this is that generation closely mirrors conditions in the economy, while capacity takes four or five years to plan and build in response to those economic conditions. As shown in Figure 28, both electric generation and installed generating capacity have tracked growth in GDP fairly closely over time, but generating capacity has done so with a lag of several years. While economic forecasts may allow plans for generating capacity to track the economy more closely, such forecasts are not always accurate and not always heeded. So new construction starts have tended to move in parallel with generation, and completions of generating capacity have lagged.

Figure 28 Growth of Generation, Generating Capacity and GDP in China, 1980-2004



Source: NBS (2003b).

FUTURE DIRECTIONS IN CHINA'S GENERATING MIX

While projections of China's future generating mix differ, most analysts agree on several scores:

- Coal will play a dominant role in the generating mix for some decades to come. Domestic coal is cheap and abundant, so other options cannot easily compete.[86]
- Gas-fired power plants should play a small but growing role in the generating mix over time, despite relatively high costs, because of their superior environmental performance, short construction time and flexibility to follow loads up and down.
- Oil use for power generation will continue to be marginal due to price volatility and government policies to limit such use. East coast areas will keep a few diesel generators and boilers fired by fuel oil for backup and peak-load adjustments.
- Hydropower is expected to provide a fifth to a quarter of China's generating capacity over the period from 2005 to 2020. Hydropower will steadily expand with completion of the gigantic Three Gorges project and seven other large-scale plants on which construction began or will begin between 2001 and 2005. But expansion of hydropower will be limited by high construction costs, long construction periods, the site-specific nature of each plant, and impacts on the riverine environment.[87]

[86] IEA (2002a).

[87] SETC (2002b).

- Renewable energy sources other than hydro will play but a modest role in China's power mix before 2020. But China has large wind resources, within reasonable distances of major cities, that could well be developed over the longer term.
- Nuclear power plants will play a growing but modest role, despite their capital intensity and long construction times, due to their inclusion in national plans. By 2020, 28 new plants are to be added to 9 in service, so that nuclear capacity expands from 7 GW to 32 GW, coming to generate 4 percent of the economy's electricity.[88]

As can be seen from Table 45, construction of coal-fired powerplants continues to proceed at a rapid pace. The amount of new coal-fired capacity fell by half between 2000 and 2002 but then grew more than four-fold in 2003 to more than double 2000 levels. Construction began on roughly 20 percent more coal-fired capacity in 2004 than in 2003. Expansion of coal-fired power should remain strong due to moderate construction costs and low fuel costs.[89]

Table 45 Coal-Fired Powerplant Construction in China in Recent Years

Coal-fired Powerplants	Capacity	Construction Status	Location
39 Units Commissioned in 2000	13,685 MW	Completed in 2000	Various
47 Units Commissioned in 2001	11,775 MW	Completed in 2001	Various
22 Units Commissioned in 2002	6,550 MW	Completed in 2002	Various
91 Units Commissioned in 2003	31,110 MW	Completed in 2003	Various
Construction Starts in 2003	29,600 MW	2003 Start, 2006 Completion	Various
144 Construction Starts in 2004	36,700 MW	2004 Start, 2007 Completion	Various

Sources: State Power (2000), (2001), (2002). Chen (2004). NRDC(2004).

Yet despite the continued dominance of coal in the electric power sector, several recent developments should promote the use of natural gas for power production:

- The government has begun to charge fees for emissions of atmospheric pollutants, specifically sulphur dioxide and nitrogen oxides, for which emissions from coal-fired plants are greater than emissions from gas-fired plants. In 2003, the State Council raised the emissions fee by a factor of ten for sulphur dioxide and applied the same emissions fee to nitrogen oxides, which had not been taxed before.
- Serious power shortages in 2003 revealed that coal supplies can be constrained by transportation capacity and that coal prices, while low, can rise. The official price of coal to electricity producers was raised by 12 yuan (US$1.45) per tonne, and the electricity tariff was raised by 0.007 yuan per kWh to compensate.
- Gas supply options are expanding. The West-to-East gas pipeline, which can carry 12 Bcm per year, was recently completed. LNG terminals in Guangdong province will have the capacity to ship in another 8.2 Bcm per annum by 2008.
- The central government is trying to promote power generation from gas by administrative means, such as forbidding new coal-fired plants near large cities and requiring that gas be used at urban cogeneration facilities. As Table 46 indicates, 23 gas-fired plants with a capacity of more than 20 GW are to be completed by 2010, raising gas use for power generation to 24 Bcm. They will account for 11 percent of new generating capacity built between 2001 and 2010, making up 5 percent of total capacity by 2010. The power sector share of China's gas consumption will rise to nearly 30 percent by 2010 and should reach 40 to 45 percent by 2020.[90]

[88] Zhou, D. (2003). Li, Z. (2003).

[89] State Power (2000), (2001), (2002). NRDC (2004). Chen (2004).

[90] Gao (2003).

Table 46 Gas-Fired Powerplants in China Planned through 2010

Location	Capacity	Yearly Use	Gas Source
Jing-Jin-Tang Grid	**2,100 MW**	**1.8 Bcm**	**Shaanxi**
Beijing No.3 Co-gen	600 MW		
Tianjin No.1 Co-gen	300 MW		
Beijing Gaojing/Hebei Guoan	1,200 MW		
East China Grid	**9,840 MW**	**9.0 Bcm**	**West-East Pipeline**
Shanghai Zabei	600 MW		
Shanghai Zaojin	600 MW		
Nanjin Co-gen	600 MW		
Zhangjiagang	600 MW		
Jingling	900 MW		
Zhejiang Banshan	900 MW		
Zhejiang Zhenghai	740 MW		
Wenzhou	300 MW		
Zhejiang Xinchang	1,200 MW		
Central China Grid	**1,310 MW**	**1.2 Bcm**	**Sichuan**
Wuchang	189 MW		
Qingshang Co-gen	443 MW		
Shashi	210 MW		
Dunkou	178 MW		
Qingshan	112 MW		
Guangdong Grid	**3,880 MW**	**2.16 Mt**	**LNG from Australia**
Huizhou	1,980 MW		
Shenzhen Qingwan	1,020 MW		
Oil-to-Gas Switching	880 MW		
Guangxi Grid	**1,500 MW**	**2.0 Bcm**	**South China Sea**
Hainan Grid	**590 MW**	**1.6-1.8 Bcm**	**South China Sea**
Guansu Grid	**1,130 MW**	**1.1 Bcm**	**West-East Pipeline**
Total China	**20,350 MW**		

Source: Gao (2003).

On the other hand, several factors may slow the use of natural gas for power production:

- Gas is costly and provided through take-or-pay contracts, so that losses would be heavy if a gas-fired plant went out of service and could not use its contracted gas.
- Gas resources are mostly imported, with uncertainty about prices and availability.
- Gas is very clean and can therefore be used directly in homes and businesses, whereas coal requires large-scale processing to be used cleanly at a reasonable cost. Gas may thus be more economical than coal for clean, small-scale fuel use, while large-scale clean coal technologies in the power sector are cheap enough that gas cannot compete with coal for power without very high pollutant emissions charges.
- Under traditional regulation of the electric power industry, there is political pressure for the government to keep the price of electricity as low as possible, both for individual citizens and for businesses competing in international markets. This in turn creates pressure for power producers to use the lowest-cost means of production, namely coal, regardless of ancillary benefits associated with gas.
- With planned deregulation of electricity generation to boost competition in the power sector, the pressure to use the lowest-cost means of production will be even greater, unless there are special mechanisms to compensate for the higher costs of alternative fuels, such as subsidies for certain types of powerplants or portfolio standards requiring that some types of plants produce a target share of generation.

Hydropower in China is expanding steadily, albeit at a far slower pace than coal-fired power. After the expected completion of the enormous and controversial 18 GW Three Gorges Project in 2008, other hydro plants on the drawing boards are of relatively modest scale. As shown in Table 47, over 26 GW of new hydro capacity is expected to be commissioned by 2010.[91] In base-case analysis by China's Energy Research Institute (ERI), total hydroelectric capacity in service is projected to further expand from 110 GW in 2010 to 170 GW in 2020. That would include about 1 GW per annum in construction of mini-hydro plants with reduced environmental impacts. In this view, the portion of China's large-scale hydro resource potential that is economically exploited would expand from about 20 percent in 2000 to about 45 percent in 2020.

As for other renewable power sources, while the Tenth Five Year Plan endorses just 2.5 GW of new capacity by 2010, ERI estimates that there could be 15 GW of new capacity by 2020 under base-case assumptions and as much as 30 GW by 2020 if renewables are vigorously promoted.[92] The most promising non-hydro renewable option appears to be wind power, for which the National Development Reform Commission has set a goal of installing 20 GW of capacity by 2020. The goal seems realistic if current growth rates persist; by the end of 2003, China had 40 wind farms with 567 MW of installed capacity, representing a 21 percent increase from the end of 2002.

Most of China's wind-powered generating capacity is located in the windy north and west, with 127 MW in Liaoning, 104 MW in Xinjiang, and 88 MW in Inner Mongolia. But increasing amounts of wind capacity are located in southeastern coastal provinces near load centres, with 86 MW in Guangdong and 33 MW in Zhejiang. A new programme of 20-year wind power concessions, with generating capacity to be built on a build-operate-transfer basis, should promote further growth. Two concessions for 100 MW each were issued in September 2003, at competitively bid prices of 0.436 yuan (US$0.0053) and 0.501 yuan (US$0.0060) per kWh. Another ten to twenty such wind power concessions are expected to be issued through competitive bidding by the end of 2005.[93]

Table 47 Large Hydropower Plants in China: Recent Builds and Plans through 2010

Hydropower Plant	Capacity	Construction Period	Location
34 Units Commissioned in 2000	4,720 MW	Completed in 2000	Various
36 Units Commissioned in 2001	2,662 MW	Completed in 2001	Various
5 Units Commissioned in 2002	840 MW	Completed in 2002	Various
Tian Sheng Qiao	1,200 MW	1991 Start, 2000 Completion	Southwest
Hydropower Recent Builds	***9,422 MW***	***Completion 2000-2002***	***Various***
Gong Pe Xia	1,500 MW	2001 Start, 2006 Completion	Qinghai
Three Gorges	18,200 MW	1994 Start, 2008 Completion	Hubei
Hong He Zhou	1,604 MW	2003 Start, 2008 Completion	Yunnan
Hong Tan	4,200 MW	2001 Start, 2009 Completion	Guanxi
Guang Zhao	1,040 MW	2003 Start, 2009 Completion	Guizhou
Hydropower Planned Builds	***26,544 MW***	***Completion by 2010***	***Various***

Sources: State Power. State Power Information Network. China Energy Research Society.

Nuclear power in China is expanding steadily as well. As shown in Table 48, as much as 25 GW of new nuclear generating capacity may be completed before 2020, including 2GW to be finished very soon, 8 GW endorsed in the Tenth Five-Year Plan, and 15 GW of more speculative construction.[94] China's Energy Research Institute projects 32 GW of nuclear power in operation in 2020 under base-case assumptions (including all the planned and existing plants shown in the table), or as much as 40 GW by 2020 with accelerated nuclear power development.[95]

---

[91] SP (2000), (2001), (2002), (2004). CERS (2000), page 45.

[92] Zhou, D. (2003).

[93] Ku (2004).

[94] Li, Z. (2003).

[95] Zhou, D. (2003).

Table 48 Nuclear Powerplants in China: Plants in Operation and Planned

Nuclear Powerplant	Capacity	Construction Status	Location
Daya Bay (2 x 900 MW)	1,800 MW	Operational in 2003	Tbd
Qinshan I	300 MW	Operational in 2003	Zhejiang
Qinshan II (2 x 600MW)	1,200 MW	Operational in 2003	Zhejiang
Qinshan III (2 x 700 MW)	1,400 MW	Operational in 2003	Zhejiang
Ling-ao I (2 x 1,000MW)	2,000 MW	Operational in 2003	Guangdong
Tianwan I (2 x 1,000 MW)	2,000 MW	Completion in 2004/2005	Jiangsu
Sanmen (2 x 1,000 MW)	2,000 MW	Included in 10th Five-year Plan	Zhejiang
Yangjiang I (2 x 1,000 MW)	2,000 MW	Included in 10th Five-year Plan	Guangdong
Haiyang (2 x 1,000 MW)	2,000 MW	Included in 10th Five-year Plan	Shandong
Hui'an (2 x 1,000 MW)	2,000 MW	Included in 10th Five-year Plan	Fujian
Qinshan IV (2 x 1,000 MW)	2,000 MW	Under Consideration	Zhejiang
Tianwan II (2 x 1,000 MW)	2,000 MW	Under Consideration	Jiangsu
Ling-ao II (2 x 1,000 MW)	2,000 MW	Under Consideration	Guangdong
Yangjiang II, III (4 x 1,000 MW)	4,000 MW	Under Consideration	Guangdong
Jinzhouwan (2 x 1,000 MW)	2,000 MW	Under Consideration	Liaoning
Juijiang (2 x 300MW)	600 MW	Under Consideration	Jiangxi
Hainan (2 x 300 MW)	600 MW	Under Consideration	Hainan
Fuling Baitaozheng (2 x 900 MW)	1,800 MW	Under Consideration	Chongqing
Total Nuclear Additions	**25,000 MW**	**Completion before 2020**	**Various**

Source: The Institute of Energy Economics, Japan, compiled from Tenth Five-Year Plan and other Chinese documents.

For the most part, China's programmes of construction for hydropower and nuclear power plants appear to be set, at least for the next two decades, by planning authorities. There would seem to be an official view that electric power is a vital part of the economy's infrastructure and that China will need all the power it can get from whatever sources are available. Thus, hydro and nuclear construction programmes do not seem vulnerable to cutbacks stemming from detailed economic comparisons with other generating options. At the same time, since the construction programmes are so ambitious, there is relatively limited scope for accelerating them. So much of the debate about the medium- and long-term future of China's electric power sector relates to the relative roles of coal, the reliable standby, and gas, the clean but expensive newcomer. For that reason, the following chapter offers a detailed evaluation of fossil-fuelled generating costs in China.

ECONOMIC COMPARISON OF GAS AND COAL FOR POWER PRODUCTION IN CHINA

INTRODUCTION

Realistically, to what extent can coal be displaced in China's generating mix, and over what time frame? At present, coal-fired power is far cheaper than gas-fired power in China, partly because coal plant capital costs are lower than in other economies at prevailing exchange rates, but mainly because the cost of delivering natural gas by pipeline or LNG terminal is far higher, on a calorific basis, than the cost of delivering coal, of which domestic resources are cheap and abundant. This fundamental reality is unlikely to change, and indeed the fuel cost disadvantage of gas is likely to widen over the years as growing demand for gas around the world puts pressure on gas markets.

What might change, however, is the environmental valuation of powerplant emissions. Already, China has begun to charge powerplants for emissions of sulphur dioxide and nitrogen oxides. The tax on these pollutants may increase over the years, as a means of internalising their environmental and health costs to China's citizens. In addition, as concerns grow over global warming, a market value may increasingly be attached to carbon emissions. Such factors will tend to improve the cost-competitiveness of gas-fired plants vis-à-vis coal-fired plants. In addition, technologies are being developed for the removal and sequestration of carbon from both coal- and gas-fired plants. If the value of carbon rises high enough, advanced plants with carbon sequestration could well compete.

This chapter compares the costs of conventional coal-fired and gas-fired power plants under various assumptions about fuel costs, exchange rates, and the value of reducing carbon emissions. It also compares the costs of conventional fossil-fuelled plants with the costs of fossil-fuelled plants with carbon sequestration under various assumptions about charges for carbon emissions. To do so, it first explains each of the main components of generating costs: capital costs, fuel costs, operation and maintenance costs, and environmental charges. Since the comparison relates to construction of new plants, coal-fired plants are assumed to be late-model plants with flue-gas desulphurisation equipment, and gas-fired plants are assumed to be high-efficiency combined-cycle gas turbine plants.

CAPITAL COSTS OF POWERPLANTS IN CHINA

The capital cost component of generating costs for power plants depends on several factors:

- The capital construction cost per kilowatt of generating capacity;
- The cost of capital, or discount rate, which together with the amortisation period determines the percentage of construction costs that must be paid back each year;
- The assumed plant amortisation period in years, which equals the physical lifetime of the plant in economic terms but may be shorter in financial terms since banks often require that loans be repaid in less than the physical lifetime of the plant.
- The capacity factor, or the ratio of actual output to rated output in a typical year, often stated in terms of numbers of hours of operation per year at full capacity.

Multiplying the capital cost per kilowatt of capacity times the amortisation factor, which is the percentage of capital that must be paid each year in order for the sum of the discounted payments to equal the capital cost, one obtains the amount of principal repayment required per kilowatt of capacity each year. Dividing that annual principal repayment, in dollars per kilowatt, by the average number of hours of operation each year, one obtains the capital cost in dollars per kilowatt-hour.

Gas turbines have been getting cheaper as their technology develops and their market expands. Figure 29 plots the cost and efficiency of gas turbines recently built around the world. For the 81 turbines shown, the average efficiency was 33 percent and the average investment cost was US$342 per kilowatt. For many turbines built recently, the efficiency had improved to around 35 percent and the cost had declined to around $200 per kilowatt. Figure 30 plots the cost and efficiency of combined cycle gas turbine power plants, which include a gas turbine plus equipment that utilises exhaust heat from the gas turbine, thereby raising overall conversion efficiency. For the 63 plants shown, the average efficiency was 51 percent and the average investment cost was $575 per kilowatt. For many combined cycle plants built recently, the efficiency had improved to over 55 percent and the cost had declined to about $400 per kilowatt. Looking at the charts together, one can observe that the gas turbine cost represents about half the total capital cost for recent CCGT plants.[96]

Base-case capital cost assumptions for coal and gas-fired plants can be made as follows:

- Costs of US$523 per kW for a new coal plant that consists of two 600 MW units with flue gas desulphurisation (the average cost for 11 such coal plants recently built in China) and $526 per kW for two new combined cycle gas plants that each consist of two 300 MW units (the average cost for 4 recent plants in China);[97]
- A 10 percent discount rate or weighted cost of capital;
- A 25-year financial lifetime for both coal-fired and gas-fired powerplants;
- A capacity factor of 75.9 percent for both coal-fired and gas-fired powerplants, corresponding to 6,650 hours in full service out of 8,760 hours in the year.

It may be noted that the assumed base-case construction cost for combined cycle gas turbines is substantially higher than the cost of such turbines recently built elsewhere. One reason is that all large-scale gas turbines, which are high-technology equipment, must be imported; while exempted from import tax, their purchase may entail high transaction costs. Other reasons include lack of experience in CCGT plant construction, high management costs, and high training costs.

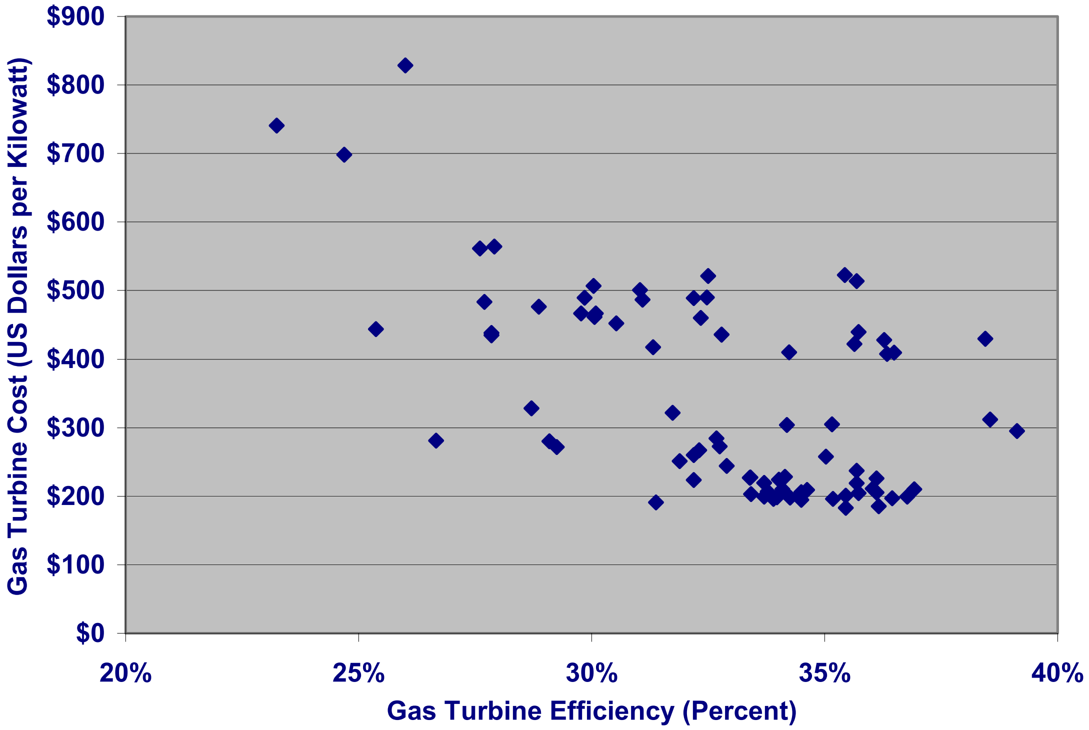
Sensitivity cases for comparing capital costs of coal and gas plants may be derived as follows:

- ***Lower-Cost, Higher-Efficiency Gas Plants:*** Based on worldwide data shown in Figure 30, it may be possible to buy combined cycle gas plants with 58 percent efficiency at $300 per kilowatt. Such substantially reduced costs would naturally tend to make gas plants more economically attractive relative to coal plants.
- ***Low Discount Rate:*** It might be possible to obtain capital at a real cost of 5 percent per annum if the government reduced risks through loan guarantees. This would tend to boost the relative attractiveness of plants with higher capital costs per kilowatt, which will be coal-fired powerplants under most reasonable assumptions.
- ***Stronger Currency:*** The Chinese yuan could conceivably double in value against a trade-weighted basket of currencies over the next two decades. Since the capital costs of coal plants are encountered almost entirely within the domestic economy, and initially denominated in yuan, this would imply a doubling of capital costs per kilowatt for such plants in dollar terms. Since about half the capital cost of combined cycle gas plants consists of the cost of the gas turbine, as shown above, and since the gas turbine is imported, half the cost of such plants would remain constant, so that the overall costs of such plants would rise by just half in dollar terms. A stronger currency would thus tend to make gas plants more attractive.
- ***Economic Lifetimes:*** In reality, coal-fired powerplants have historically proven more durable than gas-fired plants. If the amortisation period is based on physical lifetimes of 40 years for coal plants and 20 years for gas plants, instead of financial lifetimes of 25 years for both types of plants, annual payments will decline for coal plants and increase for gas plants, tending to make coal plants more attractive.

[96] China Energy Network (2003a) and (2003b).

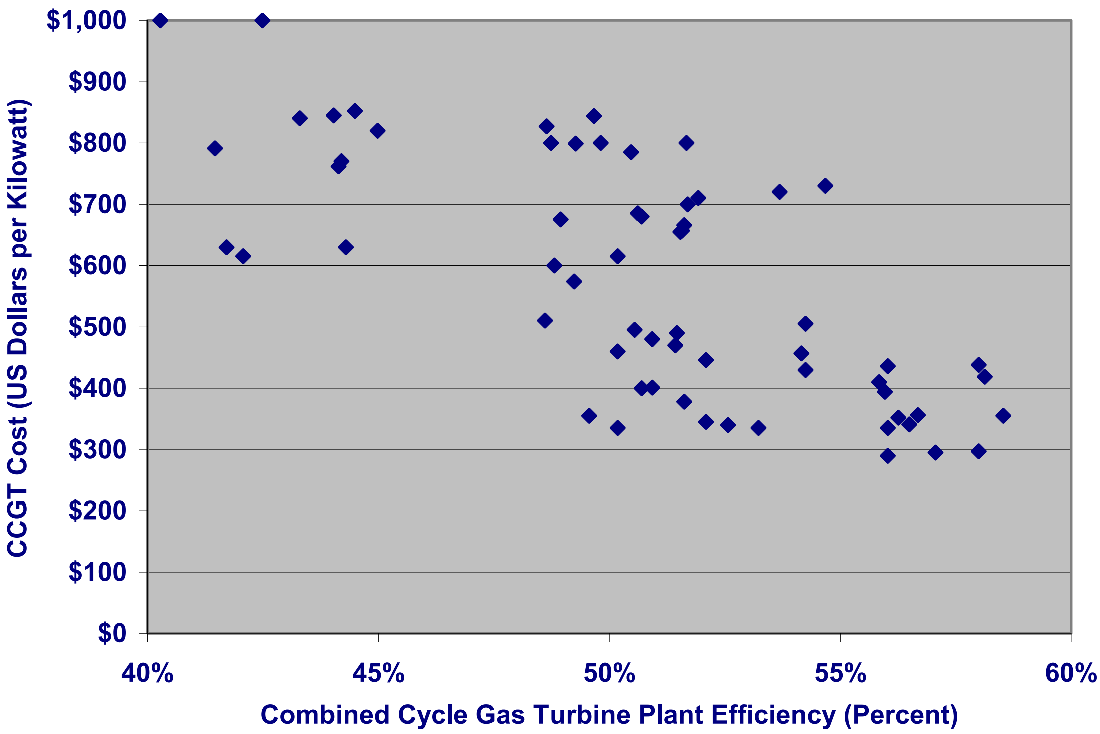
[97] Hitachi Engineering Company, Ltd (2003), pages 4-15.

Figure 29 Scatter Plot of Cost and Efficiency of New Gas Turbines Around the World



Source: China Energy Network (2003a). Note: Each dot represents a single constructed CCGT power plant.

Figure 30 Cost and Efficiency of Combined Cycle Gas Turbine Power Plants: Scatter Plot for Recently Built CCGT Plants Around the World



Source: China Energy Network (2003b). Note: Each dot represents a single constructed CCGT power plant.

Results of various capital cost comparisons for coal- and gas-fired plants are shown in Table 49. Under base case assumptions, capital costs for the two types of plants are equal. But under most plausible alternative assumptions, capital costs for gas-fired plants are substantially lower:

- ***Base Case Coal with Base Case and Low-Cost Gas Plants:*** In the base case analysis, both coal- and gas-fired plants have capital costs of US$0.0087 per kWh. With lower capital costs per kW, gas plant capital cost declines to $0.0050/kWh, so the cost of gas plants relative to coal plants is reduced by $0.0037/kWh.
- ***Low Discount Rate:*** With a 5 percent discount rate instead of 10 percent, the capital cost of both coal- and gas-fired plants declines to $0.0056/kWh assuming base case capital costs per kW. With lower capital costs per kW, gas plant capital cost declines to $0.0032/kWh, giving gas plants a capital cost advantage of $0.0024/kWh, a smaller advantage than when a base case discount rate is assumed.

Table 49 Estimated Capital Costs of New Coal- and Gas-Fired Powerplants in China

Plant Type and Cost Assumptions	Capital Cost/ kW	Discount Rate	Plant Lifetime	Annual Payback	Annual Hours	Capital Cost/ kWh
Coal Base Case	$523	10%	25 years	11.02%	6,650	$0.0087
Gas Base Case	$526	10%	25 years	11.02%	6,650	$0.0087
Gas Low Cost	$300	10%	25 years	11.02%	6,650	$0.0050
Coal Low Discount Rate	$523	5%	25 years	7.10%	6,650	$0.0056
Gas Low Discount Rate	$526	5%	25 years	7.10%	6,650	$0.0056
Gas Low Discount Rate, Low Cost	$300	5%	25 years	7.10%	6,650	$0.0032
Coal High Yuan	$1,046	10%	25 years	11.02%	6,650	$0.0173
Gas High Yuan	$789	10%	25 years	11.02%	6,650	$0.0131
Gas High Yuan, Low Cost	$450	10%	25 years	11.02%	6,650	$0.0075
Coal Low DR, High Yuan	$1,046	5%	25 years	7.10%	6,650	$0.0112
Gas Low DR, High Yuan	$789	5%	25 years	7.10%	6,650	$0.0084
Gas Low DR, High Yuan, Low Cost	$450	5%	25 years	7.10%	6,650	$0.0048
Coal 40-Year Lifetime	$523	10%	40 years	10.23%	6,650	$0.0080
Gas 20-Year Lifetime	$526	10%	20 years	11.75%	6,650	$0.0093
Gas 20-Year Lifetime, Low Cost	$300	10%	20 years	11.75%	6,650	$0.0053
Coal Low DR, High Yuan, 40-Year Life	$1,046	5%	40 years	5.83%	6,650	$0.0092
Gas Low DR, High Yuan, 20-Year Life	$789	5%	20 years	8.02%	6,650	$0.0095
Gas Lo DR, Hi Yuan, 20-Year, Low Cost	$450	5%	20 years	8.02%	6,650	$0.0054

- ***Strong Currency:*** With a doubling in the value of the yuan, the capital cost doubles to $0.0173/kWh for coal plants but rises by only half to $0.0131/kWh for gas plants, giving gas plants a capital cost advantage of $0.0042/kWh over coal plants. With lower capital costs of $450 per kW (an increase by half from $300 per kW), the capital cost of gas plants would be just $0.0075/kWh, so that the capital cost advantage of gas plants over coal plants would widen to $0.0098/kWh.
- ***Low Discount Rate and Strong Currency:*** If the previous two cases are combined, with both a 5 percent discount rate and a doubling in the value of the yuan, the capital cost rises to $0.0112/kWh for coal plants and falls to $0.0084/kWh for gas plants. This gives gas plants a capital cost advantage of $0.0028/kWh over coal plants. If lower-cost gas plants are assumed, the capital cost for gas plants is just $0.0048/kWh, so their capital cost advantage widens to $0.0064/kWh.
- ***Economic Lifetimes:*** Basing the analysis on a physical lifetime of 40 years for coal plants and 20 years for gas plants instead of a financial lifetime of 25 years for both types of plants, the capital cost with base-case capital costs per kW falls to $0.0080 for coal plants and rises to $0.0093 for gas plants, giving coal plants a capital cost advantage of $0.0013. But if lower-cost gas plants are assumed, the capital cost falls to $0.0053 for gas plants, giving them an advantage of $0.0027.

- ***Low Discount Rate, Strong Currency and Economic Lifetimes:*** Combining assumptions of the previous two bullets, with a 5 percent discount rate, a doubling in the yuan's value, and physical lifetimes of 40 years for coal plants and 20 years for gas plants, the capital cost rises slightly to $0.0092 for coal plants and $0.0095 for gas plants, giving coal plants a capital cost advantage of $0.0003. But if lower-cost gas plants are assumed, the capital cost falls to $0.0054 for gas plants, giving them a capital cost advantage of $0.0038.

FUEL AND OPERATING COSTS FOR POWERPLANTS IN CHINA

The fuel cost component of generating costs for power plants depends on several factors:

- The basic cost per physical unit of fuel, such as dollars per tonne of coal or dollars per thousand cubic metres of gas;
- The heat content of fuel per physical unit, such as million British thermal units (MBtu) per tonne of coal or MBtu per thousand cubic metres of gas;
- The efficiency with which fuel is burned in the generating plant, or the fraction of the fuel's energy content that is converted to energy in the form of electricity (often expressed, inversely, as the plant's heat rate or Btu of fuel input required per kilowatt-hour of electrical output, where a kilowatt-hour equals 3,412 Btu).

Dividing the cost per physical unit of fuel by the heat content per physical unit, one obtains the fuel cost per MBtu. Further dividing the fuel cost per MBtu by the heat rate in MBtu per kilowatt-hour, one obtains the fuel cost component of generating cost in dollars per kilowatt-hour.

Coal prices are generally lower in China than in other economies, but they vary substantially. Table 50 shows the costs of coal delivered from Shanxi to the north and south, including minemouth, transportation and other costs. Prices are around US$27.70 per tonne in the north, which is closer to coal mines, and range up to $44.60 per tonne in the south, which is further away.[98]

Table 50 Regional Coal Price Components in North and South China, 2002

Coal Price Component	Price per Tonne, North	Price per Tonne, South
Minemouth Price, Shanxi	63 yuan ($7.59)	63 yuan ($7.59)
Coal Development Foundation Charge	41 yuan ($4.94)	41 yuan ($4.94)
Transport and losses from coal mines to railways	41 yuan ($4.94)	41 yuan ($4.94)
Railway shipping tariff	85 yuan ($10.24)	195-225 yuan ($23.49-$27.11)
Total Price	**230 yuan ($27.70)**	**340-370 yuan ($41.00-$44.60)**

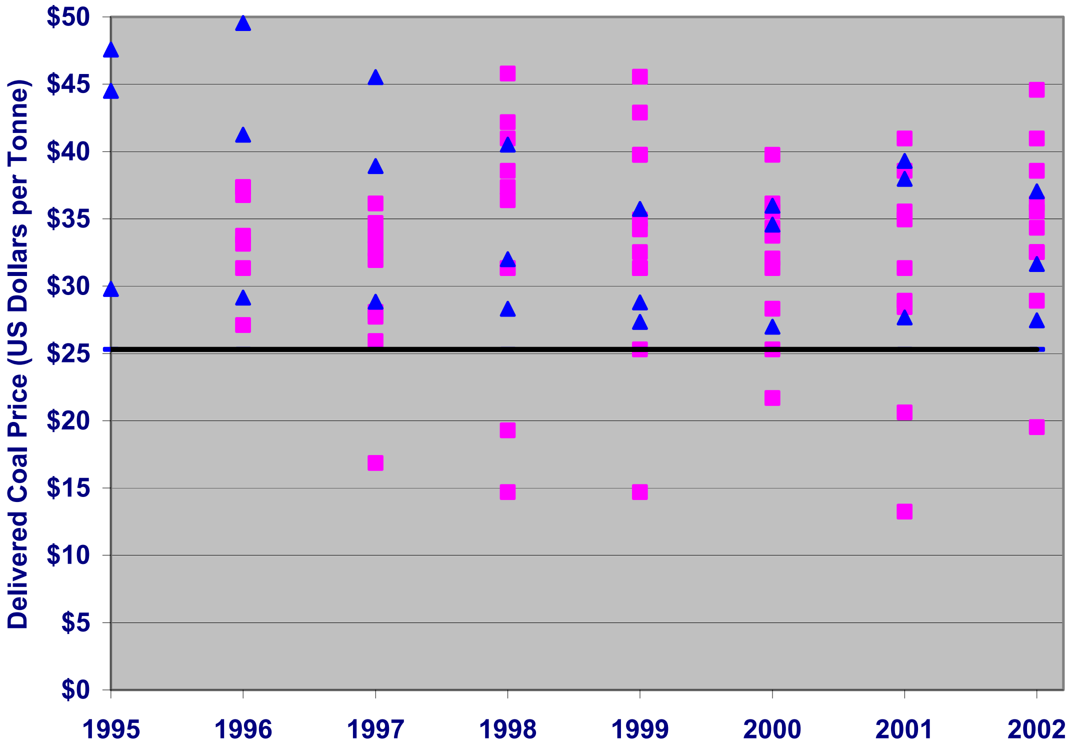
Source: Tianjin Coal Association Network (2003).

Figure 31 shows how coal prices to electricity generators compare for various parts of China and the world over time. China's average steam coal price in 2002 was 136 yuan or US$16.50 per tonne, but transportation costs raised the average price for powerplants to 210 yuan or $25.30 per tonne. As the figure shows, 2002 power sector coal prices varied considerably, from $20 to $45 per tonne. Delivered power sector prices were relatively high in the south and east, generally above $35 per tonne, and lower in the north and northeast, at or below $30 per tonne.

Natural gas in China is much more expensive than coal. Domestic resources are located in remote areas with high development costs, and the potential for their further development is limited. Thus, expansion of gas use at the margin will require reliance on imports through pipelines or LNG terminals. This will require transportation over considerable distances from places such as Australia, Brunei Darussalam, Indonesia, Russia and Central Asia, adding significantly to costs.

[98] BP (2003). CERS (2002). Zhou, Y. (2003). Tianjin Coal Association Network (2003).

Figure 31 Delivered Coal Price to Electricity Generators in China and Elsewhere



Sources: BP (2003), CERS (2002), Zhou, Y. (2003). **Pink** marks show city steam coal prices in China at Beijing, Shijiazhuang, Shenyang, Dalian, Shanghai, Nanjing, Hangzhou, Wuhan, Xiamen, Guangzhou, Xi'an and Chengdu. **Blue** marks show steam coal prices in Japan, United States and Northwestern Europe. **Black** line shows average price at power plants in China. Exchange rate 8.3 yuan per US$.

Figure 32 compares natural gas prices in China and other economies. The government recently decided that prices for gas from the West-to-East pipeline should range from 1.1 to 1.2 yuan per cubic metre, depending on the location of delivery, including wellhead cost of 0.48 yuan per cubic metre and transportation charges to powerplants. This converts (at 8.3 yuan per dollar and 0.036 Million Btu per cubic metre) to a range of US$3.68 to $4.02 per MBtu, shown by the pink and blue bars in the figure.[99] Recent research in China indicated that with gas at 0.9 yuan per cubic metre, or $3.01 per Mtu, costs of coal- and gas-fired power would be equal. This is about the $3 contract price for LNG delivered to ports in the province of Guangdong, as shown by the orange bar.[100]

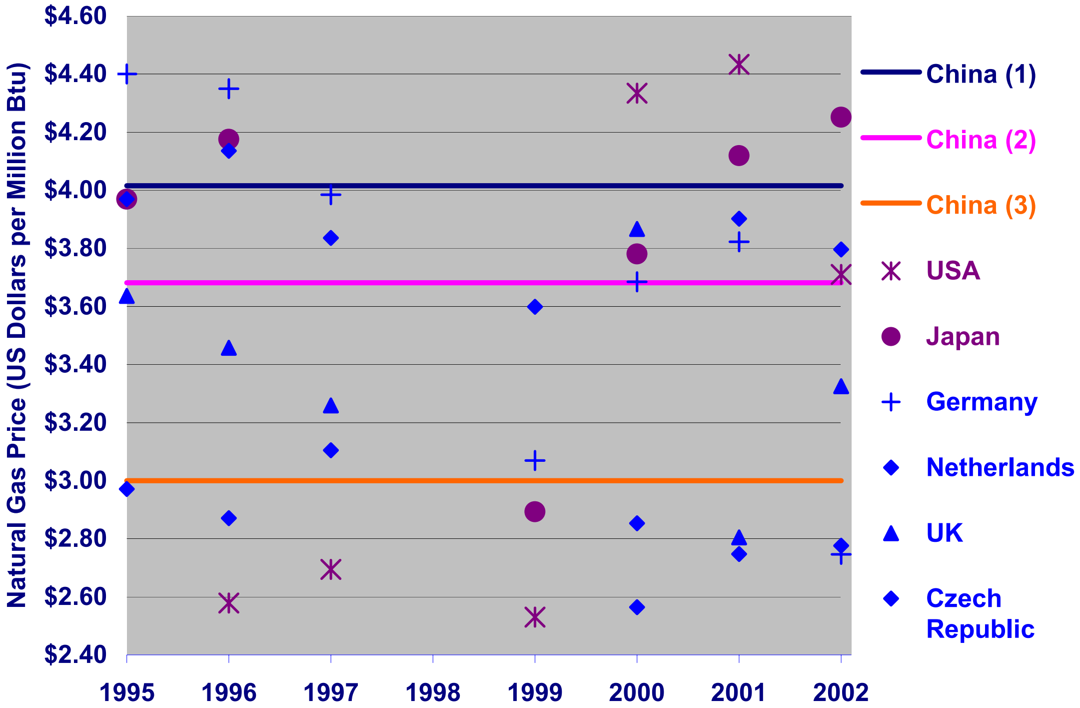
Base-case fuel cost assumptions for coal- and gas-fired plants can now be made as follows:

- Physical costs of 1.15 yuan or $0.1386 per cubic metre for natural gas (the price midpoint for gas from the West-to-East Pipeline), 230 yuan or $25.30 per tonne of coal on average, and $45.00 per tonne of coal in the areas furthest from coal mines;
- Heat content of 0.036 MBtu per cubic metre of gas, 21.82 MBtu per tonne of coal;
- Resulting costs of $3.85 per MBtu for gas, $1.16 for coal delivered to powerplants on average, and $2.06 for coal delivered to powerplants far from coal mines;
- Efficiencies of 36 percent for coal plants and 50 percent for gas plants, implying heat rates of 9,478 Btu/kWh for coal plants and 6,824 Btu/kWh for gas plants.

[99] IEA (2003b). Chang (2003). The wellhead cost component will be adjusted based on a five-year weighted average of changes in the prices of crude oil (40 percent), LPG (20 percent) and coal (40 percent), with the adjustment limited to 8 percent per annum. The transport cost component will be adjusted every three years, based on actual cost experience.

[100] Cui and others (2003). Schneider (2003).

Figure 32 Natural Gas Price Comparisons between China and Other Economies



Source: Natural Gas Information 2003 Edition, IEA. **China (1)** and China (2) correspond to high and low ends of the price range for natural gas from the West--East pipeline. China (3) corresponds to the price of LNG delivered to Guangdong province.

Sensitivity cases for comparing the fuel costs of coal and gas plants may be derived as follows:

- ***Lower Gas Fuel Cost:*** A plant located on the coast might be able to obtain gas more cheaply, perhaps as low as the LNG price of $3 per MBtu in Guangdong. Cheaper gas might help gas plants compete more effectively against coal plants.
- ***Higher Gas Plant Efficiency:*** The most efficient gas-fired powerplants have operated at efficiencies as high as 58 percent, reducing fuel costs per kilowatt-hour.

Results of various fuel cost comparisons for coal- and gas-fired plants are shown in Table 51.

- ***Base Case Coal and Gas Plants:*** In the base case analysis, fuel costs per kWh are estimated at $0.0263 for typical gas plants, $0.0110 for average coal-fired plants, and $0.0195 for coal plants far away from coal mining areas. Average coal plants thus have a fuel cost advantage of $0.0153/kWh over typical gas plants, and even coal plants with the costliest fuel have a fuel cost advantage of $0.0068/kWh.
- ***Low Gas Fuel Cost:*** If gas could be obtained for $3 per MBtu, the fuel cost of gas plants would fall to $0.0205/kWh, reducing the fuel cost advantage of coal plants to $0.0095/kWh on average and $0.0010/kWh where coal is most costly.
- ***High Gas Plant Efficiency:*** If new gas plants operated at 58 percent efficiency, their fuel cost would fall to $0.0226/kWh, reducing the fuel cost advantage of coal plants to $0.0116/kWh on average and $0.0031/kWh where coal is most costly.
- ***Low Gas Cost and High Gas Efficiency:*** If the previous two cases are combined, with both a gas price of $3/MBtu and 58 percent gas plant efficiency, the fuel cost of gas plants would fall to $0.0176/kWh, narrowing the average fuel cost advantage of coal plants to $0.0066/kWh and giving gas plants a rare fuel cost advantage of $0.0019/kWh over coal plants in areas most distant from coal mines.

Table 51 Estimated Fuel Costs of New Coal- and Gas-Fired Powerplants in China

Plant Type and Cost Assumptions	Fuel Cost Per Unit	Fuel MBtu Per Unit	Fuel Cost Per MBtu	Plant Efficiency	Heat Rate, Btu Per kWh	Fuel Cost Per kWh
Coal Base Case, Average	$25.30/t	21.82 MBtu/t	$1.16/MBtu	36%	9,478	$0.0110
Coal Base Case, High	$45.00/t	21.82 MBtu/t	$2.06/MBtu	36%	9,478	$0.0195
Gas Base Case	$0.1386/m^3	0.036 MBtu/m^3	$3.85/MBtu	50%	6,824	$0.0263
Gas Low Fuel Cost	$0.1080/m^3	0.036 MBtu/m^3	$3.00/MBtu	50%	6,824	$0.0205
Gas High Plant Efficiency	$0.1386/m^3	0.036 MBtu/m^3	$3.85/MBtu	58%	5,882	$0.0226
Gas Low Cost, High Efficiency	$0.1080/m^3	0.036 MBtu/m^3	$3.00/MBtu	58%	5,882	$0.0176

Maintenance costs for powerplants are typically estimated as a function of capital costs. The more equipment there is at the plant, the more maintenance is required. As a rule of thumb, total maintenance costs may be assumed to equal 2.5 percent of the capital cost for a typical plant. So such costs can be approximated simply by multiplying the capital cost figures in Table 49 by 0.025. Under base case assumptions, the maintenance costs would work out to roughly $0.00022 per kWh for coal-fired and gas-fired plants alike. Under alternative assumptions, the type of plant with a capital cost advantage will have a proportionate but much smaller maintenance cost advantage.

Manpower and other operating costs at powerplants are usually fixed amounts per plant per year. This analysis assumes annual operating costs per plant of US$1.32 million for coal plants and US$1.02 million for gas plants with 1,200 MW of capacity. Operating 6,650 hours per year, this amount of capacity will generate 7.98 billion kWh per year. Dividing by that number of kWh, operating costs are found to be $0.0001654/kWh for coal plants and $0.0001278/kWh for gas plants. These amounts are obviously quite negligible compared with other cost components.

ENVIRONMENTAL CHARGES FOR POWERPLANTS IN CHINA

China has instituted charges on emissions of major atmospheric pollutants from all sources, with effect from July 2004 for nitrogen oxides and from July 2003 for other pollutants including sulphur dioxide, dust, carbon monoxide, mercury and soot. A standard fee of 0.6 yuan is levied on each unit of "pollutant standard equivalent" (PSE). The more powerful the pollutant, the less of it is needed to constitute one PSE. For example, while 16.7 kg of carbon monoxide are needed to equal one PSE, just 0.0001 kg of mercury are needed. The fees now in place for various pollutants, the amount of pollutant per PSE, and the equivalent charge per kilogramme of pollutant are shown in Table 52. Each facility currently pays fees on its top three pollutants in terms of PSEs; for electric powerplants, these are sulphur dioxide, nitrogen oxides and dust.

Regulations also require that all new coal-fired powerplants install flue gas desulphurisation (FGD) equipment. At present, the fee per unit of SO_2 emissions is deliberately set to equal the estimated cost per unit of desulphurisation, so that the installation of FGD "scrubbers" no longer carries an effective penalty. In future, the fee per unit of SO_2 emissions may be raised so that there is actually a positive financial incentive for the installation of desulphurisation equipment.

Table 52 Fees on Emissions of Atmospheric Pollutants in China

Pollutant	Fee per Unit Pollutant Standard Equivalent	Kg Pollutant per Pollutant Standard Equivalent	Fee per Kilogramme of Pollutant
Sulphur Dioxide (SO_2)	0.6 yuan/ PSE	0.95 kg SO_2 / PSE	0.632 yuan/ kg SO2
Nitrogen Oxides (NOx)	0.6 yuan/ PSE	0.95 kg NOx / PSE	0.632 yuan/ kg NOx
Dust	0.6 yuan/ PSE	4.0 kg Dust / PSE	0.150 yuan/ kg Dust
Carbon Monoxide (CO)	0.6 yuan/ PSE	16.7 kg CO / PSE	0.036 yuan/ kg CO
Mercury (Hg)	0.6 yuan/ PSE	0.0001 kg Hg / PSE	6,000 yuan/ kg Hg
Soot	0.6 yuan/ PSE	2.18 kg Soot / PSE	0.275 yuan/ kg Soot

Source: State Environmental Protection Administration (2003).

Table 53 shows the current impact of emissions charges on sulphur dioxide, nitrogen oxides and dust on the cost per kilowatt-hour of electricity from coal- and gas-fired powerplants. For each pollutant, the charge per kWh is calculated by multiplying an emissions factor in kg per kWh by the emissions charge per kg from the preceding table, assuming currency conversion of 8.3 yuan per dollar. Total environmental charges are less than $0.0016/kWh for coal plants and $0.00004/kWh for gas plants. If the value of the yuan were to double, the environmental charges expressed in dollar terms would also double, to $0.0031/kWh for coal plants and nearly $0.0001/kWh for gas plants. While the charges are quite small at present, they might well increase in the future.[101]

Table 53 Environmental Charges on New Coal- and Gas-Fired Powerplants in China

Type of Charge and Plant And Other Assumptions	Emissions, Kilogrammes Per Kilowatt-Hour	Emissions Charge Per Kilogramme	Emissions Charge Per Kilowatt-Hour
SOx Charge, Coal Plant	0.01737 kg/kWh	$0.07609 / kg	$0.001322 / kWh
NOx Charge, Coal Plant	0.00030 kg/kWh	$0.07609 / kg	$0.000228 / kWh
NOx Charge, Gas Plant	0.00005 kg/kWh	$0.07609 / kg	$0.000038 / kWh
Dust Charge, Coal Plant	0.00020 kg/kWh	$0.01807 / kg	$0.000004 / kWh
Dust Charge, Gas Plant	0.00005 kg/kWh	$0.01807 / kg	$0.000001 / kWh
Total Charge, Coal Plant			**$0.001554 / kWh**
Total Charge, Gas Plant			**$0.000039 / kWh**

Sources: NOx and dust emissions factors from Logan (1999a) and (1999b). Desulphurisation cost from Liu, P. (2003).

Note: SOx charge here includes both the charge applied to the 10% of SOx that is emitted and the cost of controlling the 90% of SOx so that it is not emitted, though the latter is actually a control cost rather than an emissions charge. SOx emissions factor for a coal plant is obtained by first dividing the heat rate of a 36% efficient coal plant (9,478 Btu/kWh) by the assumed heat content of coal (21,820 Btu/kg) to obtain 0.434 kg of coal consumed per kWh, then multiplying by the 2 percent sulphur content of coal and by 2 kg of SO_2 per kg of S to arrive at 0.01737 kg SO_2 emitted per kWh.

Table 54 Incremental Capital Costs for Carbon Sequestration at Hypothetical Advanced Technology Coal- and Gas-Fired Powerplants

Plant Type and Cost Assumptions	Extra Capital Cost/ kW	Discount Rate	Plant Lifetime	Annual Payback	Annual Hours	Extra Capital Cost/ kWh
Coal Base Case	$840	10%	25 years	11.02%	6,650	$0.0139
Gas Base Case	$380	10%	25 years	11.02%	6,650	$0.0063
Gas Low Cost	$380	10%	25 years	11.02%	6,650	$0.0063
Coal Low Discount Rate	$840	5%	25 years	7.10%	6,650	$0.0090
Gas Low Discount Rate	$380	5%	25 years	7.10%	6,650	$0.0041
Gas Low Discount Rate, Low Cost	$380	5%	25 years	7.10%	6,650	$0.0041
Coal High Yuan	$1,260	10%	25 years	11.02%	6,650	$0.0209
Gas High Yuan	$570	10%	25 years	11.02%	6,650	$0.0094
Gas High Yuan, Low Cost	$570	10%	25 years	11.02%	6,650	$0.0094
Coal Low DR, High Yuan	$1,260	5%	25 years	7.10%	6,650	$0.0134
Gas Low DR, High Yuan	$570	5%	25 years	7.10%	6,650	$0.0061
Gas Low DR, High Yuan, Low Cost	$570	5%	25 years	7.10%	6,650	$0.0061
Coal 40-Year Lifetime	$840	10%	40 years	10.23%	6,650	$0.0129
Gas 20-Year Lifetime	$380	10%	20 years	11.75%	6,650	$0.0067
Gas 20-Year Lifetime, Low Cost	$380	10%	20 years	11.75%	6,650	$0.0067
Coal Low DR, High Yuan, 40-Year Life	$1,260	5%	40 years	5.83%	6,650	$0.0110
Gas Low DR, High Yuan, 20-Year Life	$570	5%	20 years	8.02%	6,650	$0.0069
Gas Lo DR, Hi Yuan, 20-Year, Lo Cost	$570	5%	20 years	8.02%	6,650	$0.0069

Source: APERC calculations with assumptions on additional capital cost from Freund (2002).

[101] Logan (1999a) and (1999b). Liu, P. (2003).

With growing concerns over global warming, charges might eventually be imposed on carbon dioxide emissions, creating incentives to install carbon sequestration technology if available. Table 54 shows the additional capital costs that would be incurred for the installation of carbon sequestration equipment under the various assumptions made earlier for basic capital costs. According to recent technical estimates, technology for carbon sequestration might be made available within the next two decades at an extra cost of US$840 per kW for coal plants and $380 per kW for gas plants, with 80 percent sequestration at the coal plants and 85 percent sequestration at the gas plants.[102] If the sequestration equipment were assumed to be manufactured half within China and half in other economies, a doubling of China's currency value per the "high yuan" sensitivity cases would increase the effective cost, in dollar terms, by half for both types of plants.

Table 55 shows the carbon charges per kWh that would be incurred by coal and gas plants, with and without carbon sequestration, under various assumptions about carbon dioxide emission fees. For coal plants, CO_2 emissions are assumed to be 880 g/kWh without sequestration and 176 g/kWh with 80 percent carbon sequestration technology. For base case gas plants, CO_2 emissions are assumed to be 370 g/kWh without sequestration and 55 g/kWh with 85 percent carbon sequestration. For low-cost, high-efficiency gas plants, CO_2 emissions are assumed to be 319 g/kWh without sequestration and 48 g/kWh with 85 percent carbon sequestration.[103]

Table 55 Hypothetical Charges for Powerplant Carbon Emissions

Plant Type and Cost Assumptions	No Sequestration, CO_2 Fee of Zero	No Sequestration, CO_2 Fee of $20/tonne	No Sequestration, CO_2 Fee of $100/tonne	Sequestration, CO_2 Fee of Zero	Sequestration, CO_2 Fee of $20/tonne	Sequestration, CO_2 Fee of $100/tonne
Coal Base Case (36% efficiency)	$0.0000	$0.0176	$0.0880	$0.0000	$0.0035	$0.0176
Gas Base Case (50% efficiency)	$0.0000	$0.0074	$0.0370	$0.0000	$0.0011	$0.0055
Gas Low Cost (58% efficiency)	$0.0000	$0.0064	$0.0319	$0.0000	$0.0010	$0.0048

Sources: Calculated by APERC from data in Logan (1999a) and (1999b).

TOTAL COST COMPARISON FOR POWERPLANTS IN CHINA

Based on the foregoing analysis, it is possible to make an overall cost comparison of gas-fired and coal-fired powerplants in China, under a variety of assumptions. The overall costs are the sum of capital, fuel, and operating costs and environmental charges. In this section, the total generating costs will be compared first under current conditions and then considering charges that might be imposed on carbon dioxide emissions, with and without carbon sequestration technology.

Table 56 compares the total generating costs of coal- and gas-fired plants by summing up the data shown earlier for capital costs in Table 49, fuel costs in Table 51, and environmental charges in Table 53, as well as operating and maintenance costs. The basic scenarios in terms of capital cost and financial assumptions are similar to those already described in the section on capital costs:

- ***Base Case:*** Financial assumptions include a 10 percent discount rate, a 25-year financial lifetime for both coal- and gas-fired plants, and a capacity factor of 75.9 percent for both types of plants, corresponding to 6,650 hours per year in service.
- ***Low Discount Rate:*** Capital can be obtained at a 5 percent discount rate.
- ***Strong Currency:*** The yuan doubles in value against the US dollar over the long term. In dollars, this doubles the capital, fuel and operating costs of coal-fired plants, which are assumed to be incurred entirely within the domestic economy. The capital cost of gas plants, about half of which is attributed to imported turbines, would increase by half, while gas fuel, assumed to be entirely imported, would not change in value, and operating costs would double for gas plants as for coal plants. Hypothetical carbon sequestration technology is assumed to be half domestic and half imported, increasing in costs in dollar terms by half.

[102] Freund (2002).

[103] *Ibid.*

- ***Low Discount Rate and Strong Currency:*** The previous two cases combined.
- ***Economic Lifetimes:*** Coal and gas plants are amortised over their likely physical lifetimes of 40 and 20 years, respectively, instead of over a 25 year financial lifetime.
- ***Low Discount Rate, Strong Currency, and Economic Lifetimes:*** Three sensitivities are here combined to assess their overall impact on comparative costs.

Within each scenario, four separate cost cases are developed:

- ***Average-Cost Coal:*** Coal plants have a capital cost of $523 per kilowatt at current exchange rates, a fuel cost of $25.30 per tonne ($1.16/MBtu) equal to the average cost of coal to power producers in 2002, and an efficiency of 36 percent.
- ***Average-Cost Gas:*** Gas plants have a capital cost of $526 per kilowatt at current exchange rates, a fuel cost of $3.85 per MBtu equal to the average cost of power producers of gas from the West-to-East pipeline, and an efficiency of 50 percent.
- ***High-Cost Coal:*** Coal plants are located far from coal mines, with fuel cost of $45 per tonne instead of $25.30 per tonne ($2.06/MBtu instead of $1.16/MBtu)
- ***Low-Cost Gas:*** Gas plants have a lower capital cost per kilowatt at current exchange rates ($300/kW instead of $526/kW), a lower fuel cost ($3.00/MBtu instead of $3.85/MBtu), and higher efficiency (58 percent instead of 50 percent).

Table 56 Estimated Total Costs of New Coal- and Gas-Fired Powerplants in China

Plant Type and Cost Assumptions	Capital Cost/ kWh	Fuel Cost/ kWh	O&M Cost/ kWh	Pollutant Cost/kWh	TOTAL Cost/kWh
Coal Base Case, High Cost	$0.0087	$0.0195	$0.0004	$0.0016	$0.0301
Coal Base Case, Average Cost	$0.0087	$0.0110	$0.0004	$0.0016	$0.0216
Gas Base Case, Average Cost	$0.0087	$0.0263	$0.0003	$0.0000	$0.0354
Gas Base Case, Low Cost	$0.0050	$0.0176	$0.0003	$0.0000	$0.0229
Coal Low Discount Rate, High Cost	$0.0056	$0.0195	$0.0003	$0.0016	$0.0269
Coal Low Discount Rate, Average Cost	$0.0056	$0.0110	$0.0003	$0.0016	$0.0184
Gas Low Discount Rate, Average Cost	$0.0056	$0.0263	$0.0003	$0.0000	$0.0322
Gas Low Discount Rate, Low Cost	$0.0032	$0.0176	$0.0002	$0.0000	$0.0210
Coal High Yuan, High Cost	$0.0173	$0.0390	$0.0008	$0.0031	$0.0602
Coal High Yuan, Average Cost	$0.0173	$0.0220	$0.0008	$0.0031	$0.0432
Gas High Yuan, Average Cost	$0.0131	$0.0263	$0.0006	$0.0001	$0.0400
Gas High Yuan, Low Cost	$0.0075	$0.0176	$0.0004	$0.0001	$0.0256
Coal Low DR, High Yuan, High Cost	$0.0112	$0.0390	$0.0006	$0.0031	$0.0539
Coal Low DR, High Yuan, Average Cost	$0.0112	$0.0220	$0.0006	$0.0031	$0.0369
Gas Low DR, High Yuan, Average Cost	$0.0084	$0.0263	$0.0005	$0.0001	$0.0353
Gas Low DR, High Yuan, Low Cost	$0.0048	$0.0176	$0.0004	$0.0001	$0.0229
Coal 40-Year Lifetime, High Cost	$0.0080	$0.0195	$0.0004	$0.0016	$0.0295
Coal 40-Year Lifetime, Average Cost	$0.0080	$0.0110	$0.0004	$0.0016	$0.0210
Gas 20-Year Lifetime, Average Cost	$0.0093	$0.0263	$0.0004	$0.0000	$0.0360
Gas 20-Year Lifetime, Low Cost	$0.0053	$0.0176	$0.0003	$0.0000	$0.0232
Coal Lo DR, Hi Yuan, 40-Year, Hi Cost	$0.0092	$0.0390	$0.0006	$0.0031	$0.0518
Coal Lo DR, Hi Yuan, 40-Year, Avg,Cost	$0.0092	$0.0220	$0.0006	$0.0031	$0.0348
Gas Lo DR, Hi Yuan, 20-Year, Avg. Cost	$0.0095	$0.0263	$0.0005	$0.0001	$0.0364
Gas Lo DR, Hi Yuan, 20-Year, Low Cost	$0.0054	$0.0176	$0.0004	$0.0001	$0.0235

Several observations may be made from the data presented in Table 56:

- ***Base Case:*** With average gas and coal plant costs, total generating cost is 64 percent higher for gas than coal, appearing to confirm the basic wisdom that gas cannot effectively compete. But with lower gas costs (including assumptions about lower plant capital costs, lower fuel costs, and higher plant efficiency) and higher coal costs (representing likely costs in regions more remote from coal mining areas), gas-fired power could have as much as a 24 percent cost advantage. Thus, the possibility of niche markets for gas-fired generation within China's economy cannot be ruled out, especially in coastal areas near gas and far from coal.
- ***Low Discount Rate:*** The situation is little altered from the base case. For average coal and gas plants, costs per kW are virtually identical, so costs per kWh are affected in almost the same way by a reduced cost of capital. Even with lower gas plant costs per kW, capital costs do not make up a large enough share of total costs for a lower cost of capital to improve the relative position of gas by much.
- ***Economic Lifetimes:*** Again, the situation is little changed from the base case. Extending the amortisation period to 40 years for coal plants and reducing it to 20 years for gas plants has little impact on annualised capital costs or costs per kWh.
- ***Strong Currency:*** A doubling of the yuan's value could make gas-fired powerplants far more competitive, giving them a slight edge over coal-fired plants even under average cost conditions. Under low cost assumptions, gas plants could undercut coal-fired power in areas remote from coal production by more than half. The picture is little changed if a strong yuan is combined with a low discount rate (and would also be similar if a strong yuan coincided with a high discount rate).
- ***Combined Sensitivities:*** If low discount rates, amortisation over economic lifetimes and strong currency cases are combined, gas-fired power is only slightly more expensive than coal-fired power under average cost conditions and far cheaper in areas where low-cost gas can compete with high-cost coal.

The picture changes considerably if carbon taxes are introduced and carbon sequestration technology becomes available. Table 57 compares the total costs of generation from coal-fired power plants both with and without carbon sequestration technology, assuming carbon taxes of zero, \$20 and \$100 per tonne of CO_2. When carbon taxes are absent, the additional cost of installing carbon sequestration technology is obviously not warranted, and the competitive positions of coal and gas remain as they were before. But when carbon taxes reach \$20 per tonne of CO_2, the impact is striking: costs are quite similar with and without sequestration, they are also often quite similar for both coal and gas plants, and the cost advantage of coal-fired power under average cost conditions nearly evaporates. When carbon taxes reach very high levels, carbon sequestration becomes imperative, and gas looks a lot better than coal in most instances.

Regarding the impact of a \$20 tax per tonne of carbon dioxide, the following may be observed:

- ***Coal loses most of its cost advantage:*** The cost premium for gas fired power under average cost conditions narrows from 64 percent to 9 percent in the base case, from 75 percent to 10 percent with a low discount rate, and from 71 percent to 12 percent with amortisation of costs over physical lifetimes. In other cases, average cost conditions give gas-fired power a cost advantage of 16 to 22 percent.
- ***Carbon sequestration begins to make sense:*** For both coal and gas plants, sequestration clearly reduces costs in the low discount rate case, largely because the reduced cost of capital limits the financial burden of installing sequestration equipment. Sequestration has little effect on costs in the base case, the combined low discount rate and strong currency case, or the economic lifetime case.
- ***Gas could be favoured over sequestration in some cases:*** In the strong currency case, a carbon tax at this level would render coal more expensive than gas

for electricity generation, owing to its higher carbon content, but generation from gas would still be cheaper without sequestration than with it. If strong currency is combined with a low discount rate and/or amortisation over economic lifetimes, gas would have the same advantage over coal either with or without sequestration.

- ***Gas would have a huge cost advantage in some areas:*** This can be seen by comparing low cost gas-fired generation – involving plants with lower capital costs and fuel costs and higher operating efficiency – with high-cost coal-fired generation in areas remote from coal producing regions, in any of the cases shown.

With respect to the impact of a $100 tax per tonne of carbon dioxide, one can notice:

- Carbon sequestration technology becomes clearly advantageous in all cases.
- Gas is cheaper than coal for power generation in all cases as well.

Table 57 Comparing Hypothetical Costs of Coal- and Gas-Fired Powerplants in China at Various Levels of Carbon Dioxide Tax, With and Without Sequestration

Plant Type and Cost Assumptions	Cost/kWh Without Sequestration			Cost/kWh With Sequestration		
	Zero Tax	$20/t Tax	$100/t Tax	Zero Tax	$20/t Tax	$100/t Tax
Coal Base Case, High Cost	$0.0301	$0.0477	$0.1181	$0.0444	$0.0479	$0.0620
Coal Base Case, Average Cost	$0.0216	$0.0392	$0.1096	$0.0359	$0.0394	$0.0535
Gas Base Case, Average Cost	$0.0354	$0.0428	$0.0724	$0.0419	$0.0430	$0.0474
Gas Base Case, Low Cost	$0.0229	$0.0292	$0.0548	$0.0293	$0.0303	$0.0341
Coal Low Discount Rate, High Cost	$0.0269	$0.0445	$0.1149	$0.0361	$0.0396	$0.0537
Coal Low Discount Rate, Average Cost	$0.0184	$0.0360	$0.1064	$0.0276	$0.0311	$0.0452
Gas Low Discount Rate, Average Cost	$0.0322	$0.0396	$0.0692	$0.0364	$0.0375	$0.0419
Gas Low Discount Rate, Low Cost	$0.0210	$0.0274	$0.0529	$0.0252	$0.0262	$0.0300
Coal High Yuan, High Cost	$0.0602	$0.0778	$0.1482	$0.0816	$0.0851	$0.0992
Coal High Yuan, Average Cost	$0.0432	$0.0608	$0.1312	$0.0646	$0.0681	$0.0822
Gas High Yuan, Average Cost	$0.0400	$0.0474	$0.0770	$0.0497	$0.0508	$0.0553
Gas High Yuan, Low Cost	$0.0256	$0.0320	$0.0575	$0.0353	$0.0362	$0.0400
Coal Low DR, High Yuan, High Cost	$0.0539	$0.0715	$0.1419	$0.0677	$0.0712	$0.0853
Coal Low DR, High Yuan, Average Cost	$0.0369	$0.0545	$0.1249	$0.0507	$0.0542	$0.0683
Gas Low DR, High Yuan, Average Cost	$0.0353	$0.0427	$0.0723	$0.0415	$0.0426	$0.0470
Gas Low DR, High Yuan, Low Cost	$0.0229	$0.0292	$0.0548	$0.0291	$0.0300	$0.0339
Coal 40-Year Lifetime, High Cost	$0.0295	$0.0471	$0.1175	$0.0427	$0.0462	$0.0603
Coal 40-Year Lifetime, Average Cost	$0.0210	$0.0386	$0.1090	$0.0342	$0.0377	$0.0518
Gas 20-Year Lifetime, Average Cost	$0.0360	$0.0434	$0.0730	$0.0429	$0.0440	$0.0484
Gas 20-Year Lifetime, Low Cost	$0.0232	$0.0296	$0.0551	$0.0301	$0.0310	$0.0349
Coal Lo DR, Hi Yuan, 40-Year, Hi Cost	$0.0518	$0.0694	$0.1398	$0.0632	$0.0667	$0.0808
Coal Lo DR, Hi Yuan, 40-Year, Avg,Cost	$0.0348	$0.0524	$0.1228	$0.0462	$0.0497	$0.0638
Gas Lo DR, Hi Yuan, 20-Year, Avg. Cost	$0.0364	$0.0438	$0.0734	$0.0434	$0.0446	$0.0490
Gas Lo DR, Hi Yuan, 20-Year, Low Cost	$0.0235	$0.0299	$0.0554	$0.0305	$0.0315	$0.0353

Focusing on the base case assumptions, charts can be used to illustrate how fuel prices and environmental charges affect the overall comparison between gas- and coal-fired plants. Figure 33 shows how relative coal and gas prices affect the generating cost comparison when there are no emissions charges for carbon dioxide, with base case assumptions about capital and operating costs:

- Assuming average gas costs of $3.85 per MBtu, based on the delivered cost of gas from the West-to-East pipeline, coal-fired generation will be cost-competitive wherever coal can be obtained for less than $57 per tonne.

- Assuming favourable gas costs of $3.00 per MBtu, which might be obtained under optimistic conditions for LNG in coastal areas, coal-fired generation will only be cost-competitive if coal can be obtained for less than $43 per tonne.

As discussed above, average coal prices in China are around $25 per tonne, so coal is usually very cost-competitive. But some coal prices, for coal-fired powerplants far from coal mining areas, may range as high as $45 per tonne, opening up some limited prospects for gas-fired power under current market conditions.

Figure 33 Influence of Coal and Gas Prices on whether Coal-fired or Gas-Fired Generation is Most Cost Competitive under Base-Case Assumptions

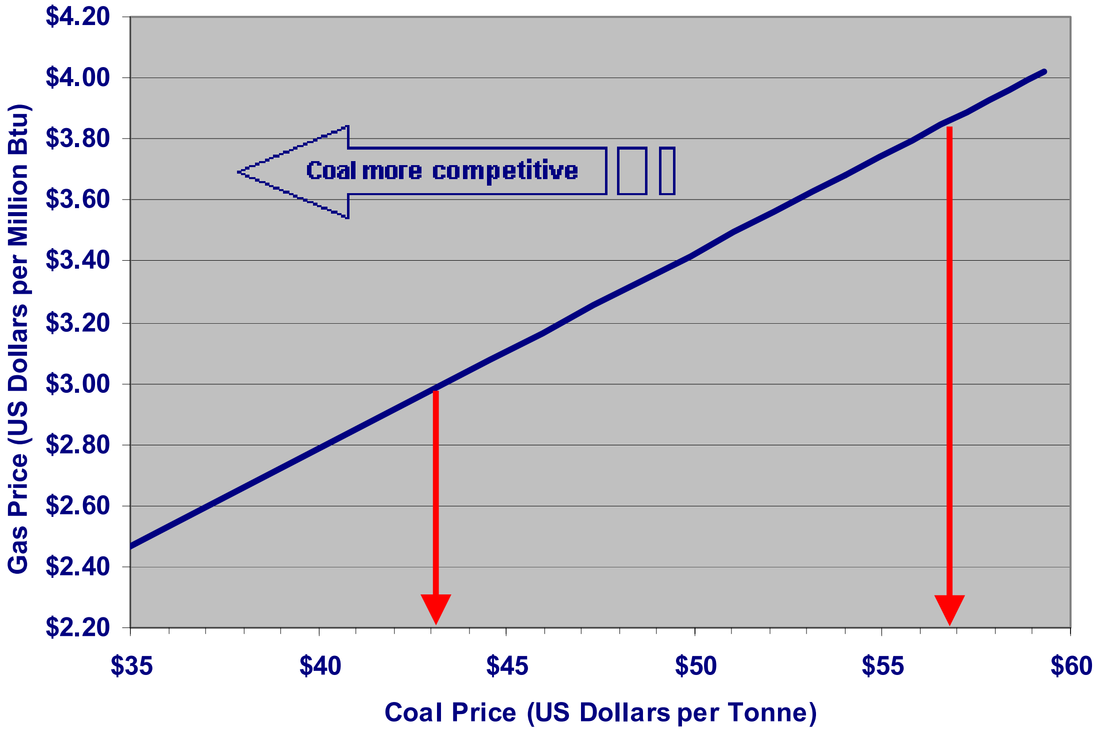
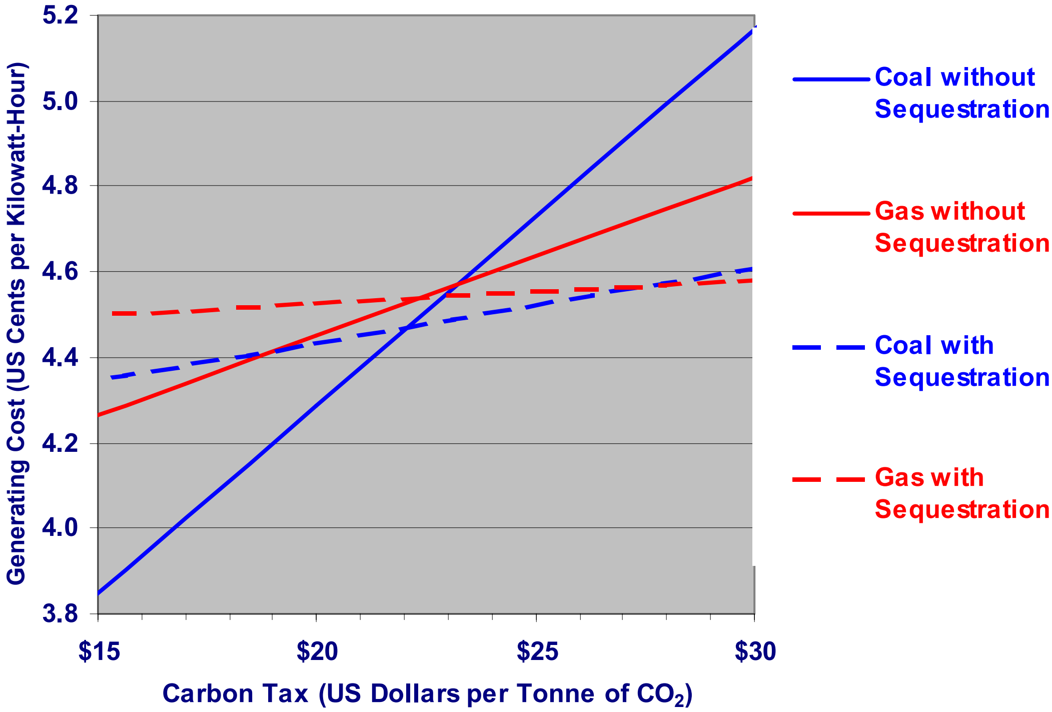


Figure 34 shows how gas- and coal-fired power compete with each other, under base-case conditions with average fuel costs, when carbon taxes and carbon sequestration technology are introduced. The following basic cost assumptions are incorporated in the figure:

- Coal-fired generation *without* sequestration costs $0.0216 per kWh prior to carbon fees, plus $0.00088 per kWh per dollar of tax imposed per tonne of carbon dioxide.
- Coal-fired generation *with* sequestration costs $0.0359 per kWh prior to carbon fees, plus $0.000176/kWh per dollar of tax imposed per tonne of carbon dioxide. The cost increases just one-fifth as much per unit of tax since sequestration technology is assumed to remove four-fifths of the carbon emissions stream.
- Gas-fired generation *without* sequestration costs $0.0354 per kWh prior to carbon fees, plus $0.00037 per kWh per dollar of tax imposed per tonne of carbon dioxide.
- Gas-fired generation *with* sequestration costs $0.0419 per kWh prior to carbon fees, plus $0.000055 per kWh per dollar of tax imposed per tonne of carbon dioxide. The cost increases just 15 percent as much per unit of tax since sequestration technology is assumed to remove 85 percent of the carbon emissions stream.

Figure 34 Comparative Costs of Coal and Gas Fired Power in China, with and without Carbon Sequestration, at Various Levels of Carbon Dioxide Tax



The figure confirms that interesting things happen when CO_2 taxes exceed $20 per tonne:

- When the CO_2 tax is below $22 per tonne, the cheapest generating option under average fuel cost conditions is coal-fired power without sequestration.
- When the CO_2 tax is between $22 and $28 per tonne, the cheapest option becomes coal with sequestration, followed closely by gas with sequestration, implying the latter option could well compete where coal is costlier than average.
- When the CO_2 tax exceeds $28 per tonne, the cheapest option becomes gas with sequestration, though coal with sequestration follows closely up to a CO_2 tax of around $35 per tonne and might thus still compete at that tax level in some areas.

CHINESE POWER SECTOR IMPACTS ON GAS AND COAL MARKETS AND THE ENVIRONMENT

INTRODUCTION

Despite some uncertainty about the pace at which gas, hydro, nuclear and other alternatives to coal-fired power are introduced to meet environmental needs, plans for various types of capacity are sufficiently advanced to give a good idea of how the generating mix will evolve over the next two decades. This chapter reviews several recent scenarios for electricity generation going forward and assesses their implications for fossil fuel demand, fossil fuel prices, and the environment.

SCENARIOS OF ELECTRICITY GENERATING MIX IN CHINA

A sense of how China's generating mix may evolve can be gleaned by a review of several recent projections. Table 58 shows the shares of generation in 2020 that different projections say will be provided by various fuels. Table 59 applies the shares to overall projections of electricity generation to arrive at projected amounts of generation from each fuel in 2020.

Key features of the various projections are as follows:

- Three projections by the Energy Research Institute show alternative views of the share of generation that might be provided by hydro and nuclear power. Scenario A makes relatively pessimistic assumptions about the future hydro and nuclear share, while scenario B makes mid-case assumptions and scenario C makes optimistic assumptions about these generating options.[104]
- An APERC scenario, from an earlier study, is close to ERI scenario C but assumes greater penetration of gas-fired power and less penetration of nuclear power.[105]
- A scenario analysed at Tsinghua University in Beijing examines a future in which gas-fired power is aggressively promoted to help meet environmental goals.[106]

Table 58 Projected Fuel Shares of Electricity Generation in China in 2020

Powerplant Type	ERI Scenario A	ERI Scenario B	ERI Scenario C	APERC Scenario	Tsinghua Scenario
Coal-Fired	72.4%	67.0%	57.1%	59.5%	55.2%
Gas-Fired	2.2%	4.2%	6.0%	8.7%	20.8%
Oil-Fired	0.3%	0.3%	0.3%	1.5%	0.1%
Hydro	18.6%	21.6%	26.6%	25.1%	21.8%
Other Renewable	0.8%	1.1%	2.4%	0.6%	0.1%
Nuclear	5.6%	5.7%	7.6%	4.6%	1.9%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Sources: ERI projections from Zhou, D. (2003). APERC (2002b). Tsinghua University projections from Guo (2003).

104 Zhou, D. (2003).

105 APERC (2003).

106 Guo (2003).

Table 59 Projected Amounts of Generation in China in 2020 by Fuel

Powerplant Type	ERI Scenario A	ERI Scenario B	ERI Scenario C	APERC Scenario	Tsinghua Scenario
Coal-Fired	2,710 TWh	2,465 TWh	1,963 TWh	1,777 TWh	1,368 TWh
Gas-Fired	82 TWh	155 TWh	206 TWh	260 TWh	516 TWh
Oil-Fired	11 TWh	11 TWh	10 TWh	45 TWh	3 TWh
Hydro	696 TWh	795 TWh	914 TWh	750 TWh	541 TWh
Other Renewable	30 TWh	41 TWh	83 TWh	18 TWh	2 TWh
Nuclear	210 TWh	210 TWh	261 TWh	137 TWh	48 TWh
Total	3,743 TWh	3,679 TWh	3,437 TWh	2,987 TWh	2,478 TWh

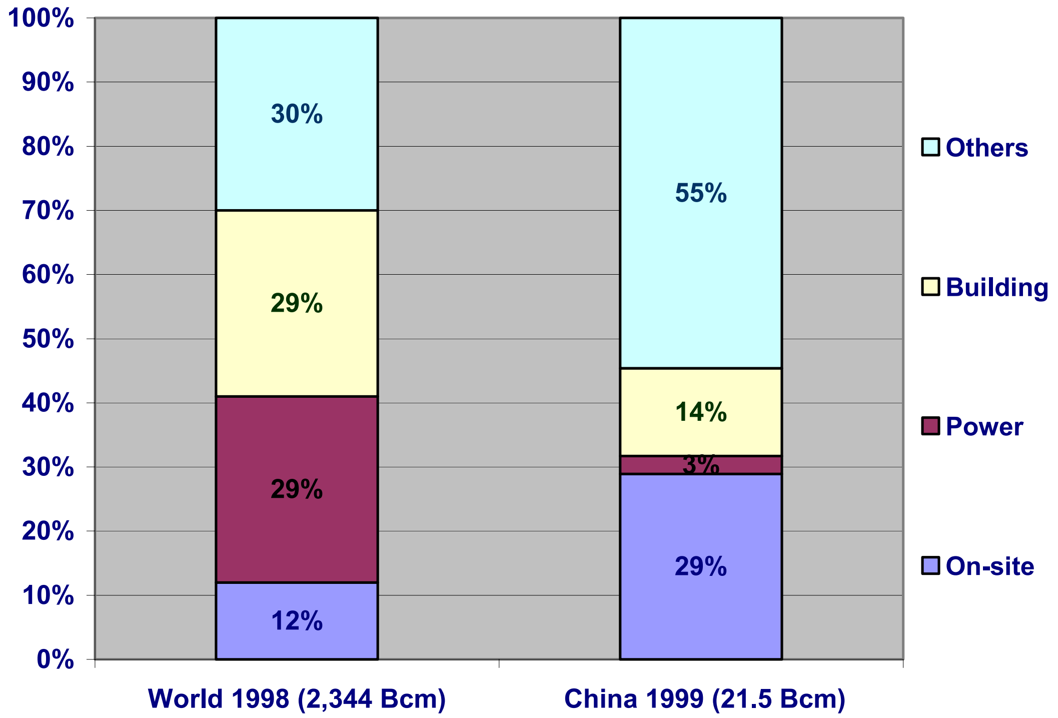
Source: APERC calculations based on Zhou, D. (2003), APERC (2002b), Guo (2003).

CHINA'S POWER SECTOR AND NATURAL GAS MARKETS

With growing use of gas for power generation, the share of natural gas in world primary energy consumption grew roughly from 18 percent in 1971 to 23 percent in 2000. IEA has projected that the share of gas will grow further to 28 percent of total primary energy use by 2030. But natural gas development did not receive much attention in China until the government decided to build the West-to-East pipeline. The share of natural gas in China's primary energy consumption decreased from 3.2 percent in 1978 to 1.7 percent in 1997 before recovering to 2.7 percent in 2002.

At present, as shown in Figure 35, China accounts for only a tiny portion of the world's gas demand, and China's electricity sector accounts for only a tiny portion of China's gas demand. In 1998, out of 2,344 Bcm of natural gas consumed worldwide, China consumed just 21.5 Bcm, or less than 1 percent. Within China, less than 3 percent of all gas was used for electricity generation, in stark contrast to the worldwide picture in which 29 percent of gas was used by the power sector.

Figure 35 Sectoral Shares of Natural Gas Use in China and the World



Source: CERS (2002).

Looking forward, however, much of the growth in China's gas use is expected to come from electricity generation, and gas use in other sectors may stagnate or grow much more slowly:

- As local gas distribution networks are constructed, the building sector will consume more gas, perhaps raising its current 14 percent share of China's gas use. Studies have shown that residential gas demand is relatively price-insensitive.[107]
- The industrial sector accounts for over half of China's gas use but actually uses only a small amount of gas, mainly as feedstock for fertiliser production. Future growth will come from use of gas as feedstock for ammonia production and as a clean fuel in the manufacture of high-quality glass and ceramics for buildings.
- On-site combustion of gas in oil and gas extraction, which accounts for over a quarter of China's gas use, will decline in importance as other gas uses expand.

The calculations performed in Table 59 above can be used to estimate the incremental natural gas demand from expanding electricity production, as well as the associated fuel bill. First, existing gas-fired generation is netted out to find incremental generation; just 5.4 TWh (5.4 billion kWh) of electricity was generated from gas in 2000.[108] The incremental generation is then multiplied by a heat rate of 6,824 Btu/kWh (0.006824 MBtu/kWh) for new gas-fired combined cycle powerplants, assumed to be 50 percent efficient. The product is then divided by the heat content of gas, 0.036 MBtu per cubic metre, to arrive at billion cubic metres of growth in annual gas demand between 2000 and 2020. Alternatively, the product is multiplied by the cost of gas in dollars per MBtu to arrive at the associated increase in annual fuel costs from new natural gas-fired powerplants.

Table 60 shows the increase in annual gas demand and fuel costs resulting from expanding electricity production between 2000 and 2020, according to each of the scenarios outlined above:

- In the ERI scenarios, yearly power sector gas demand grows 15 Bcm to 38 Bcm, depending on whether more or less hydro and nuclear power is introduced, coming to account for 13 to 21 percent of total gas use. Under the mid-case assumption that gas costs $3.85 per MBtu, like gas delivered to power producers from the West-to-East pipeline, this would mean $2.0 billion to $5.3 billion in extra gas bills each year. Under the low-case assumption that gas costs $3 per MBtu, like LNG in Guangdong, the yearly gas bill would grow by $1.6 billion to $4.1 billion.
- In APERC's scenario, yearly power sector gas demand grows 48 Bcm, coming to account for 32 percent of primary gas demand while adding costs each year of $6.7 billion at mid-case gas prices and $5.2 billion at low-case gas prices.
- In Tsinghua University's gas-focused scenario, yearly power sector gas use grows 97 Bcm, coming to account for 39 percent of gas demand. China's yearly gas bill would rise by $13.4 billion if costs are moderate and $10.5 billion if costs are low.

Table 60 Incremental Gas Demand from Electricity Generation in China, 2000-2020

Indicator	ERI Scenario A	ERI Scenario B	ERI Scenario C	APERC Scenario	Tsinghua Scenario
Incremental Gas Generation	77 TWh	149 TWh	201 TWh	255 TWh	511 TWh
Incremental Gas Demand	14.6 Bcm	28.3 Bcm	38.1 Bcm	48.2 Bcm	96.8 Bcm
Primary Gas Demand 2020	116.8 Bcm	169.3 Bcm	186.8 Bcm	151.6 Bcm	253.0 Bcm
Added Cost at $3 per MBtu	$1.6 billion	$3.1 billion	$4.1 billion	$5.2 billion	$10.5 billion
Added Cost at $3.85 /MBtu	$2.0 billion	$3.9 billion	$5.3 billion	$6.7 billion	$13.4 billion
Added Cost at $5 per MBtu	$2.6 billion	$5.1 billion	$6.9 billion	$8.7 billion	$17.4 billion

Source: APERC calculations based on Zhou, D. (2003), APERC (2002b), Guo (2003).

[107] IEA (2000)

[108] APERC (2002b), page 32 indicates 1355.6 TWh of generation in 2000, of which 1,116.4 TWh was thermal generation. Zhang (2004) shows gas accounts for under 0.49 percent of thermal generation, which would then amount to 5.4 TWh.

According to the natural gas resource survey conducted in 1994, China has fairly large gas reserves of 38 trillion cubic metres. By 2020, domestic gas output, including offshore production, is projected to reach 107 billion cubic metres.[109] But in part because of weak investment in exploration, domestic gas resources cannot support China's rapidly growing gas use at projected levels. Importing gas through LNG terminals or pipelines has thus become the strategic choice.

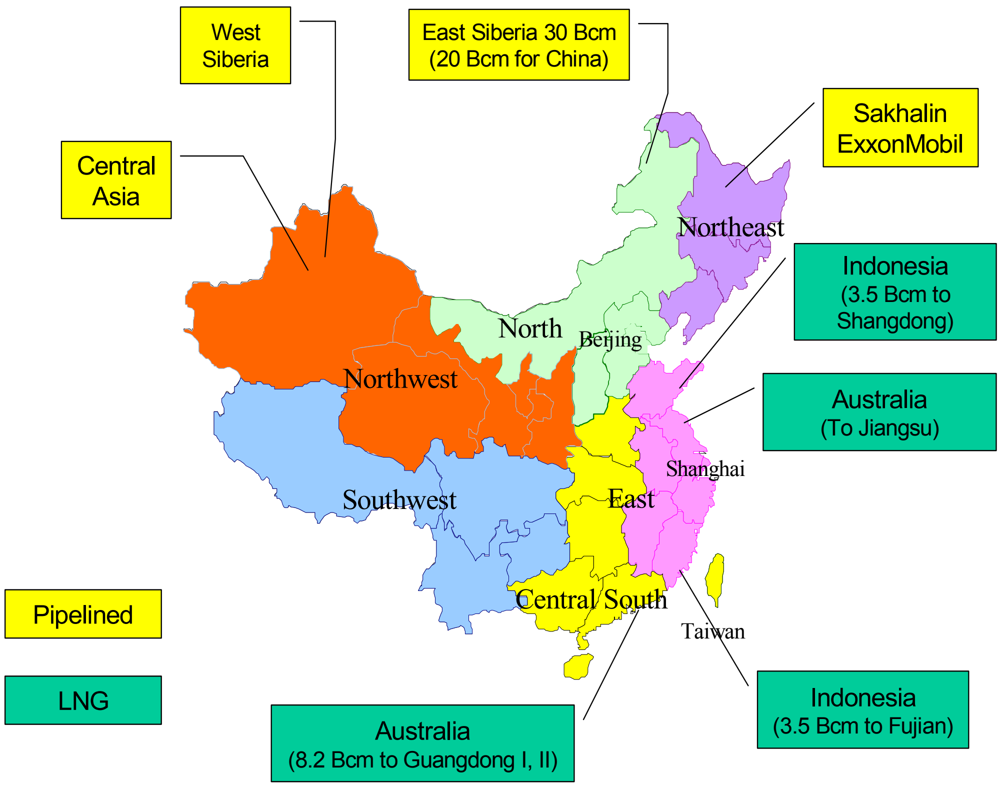
With gas production of 107 Bcm and primary gas demand between 117 Bcm and 187 Bcm as projected by ERI, China would have to import between 10 Bcm and 80 Bcm of gas, raising its gas import dependency to somewhere between 9 and 43 percent. With current import projects from Australia and Indonesia providing 11.7 Bcm, as shown in Table 61 and Figure 36, China might have to find as much as another 68 Bcm of gas import sources to meets its needs. A proposed pipeline from Russia's Far East to China and Korea would have 30 Bcm of capacity, of which 20 Bcm would be allocated to China. But that could still leave a gap of 48 Bcm to be covered by other imports. In the Tsinghua scenario, the 2020 gas import gap would widen by 66 Bcm to a total of 114 Bcm.

Table 61 China's Committed Natural Gas Import Projects as of 2003

Project	Capacity	Supplier
Guangdong LNG Phase I (2005)	4.0 Bcm/year	Australia
Guangdong LNG Phase II (2008)	4.2 Bcm/year	Australia South China Sea
Fujian LNG (2007)	3.5 Bcm/year	Indonesia
Total	11.7 Bcm/year	

Source: Yan (2003).

Figure 36 Natural Gas Import Map of China



Source: Drawn by APERC with data from Yan (2003).

[109] Jia and others (2002), pages 263, 269.

LNG trade in Asia currently accounts for about 70 percent of global LNG trade volume, with Japan alone accounting for nearly one half of global LNG trade and Korea for about another sixth. China is in a good position for importing LNG since several APEC member economies, like Australia, Brunei, Indonesia and Malaysia, are the world's major LNG suppliers.

Recent gas price volatility in North America, and a worldwide trend of rising gas prices, have raised the issue of long-term gas supply security. But for several reasons, the chances of a gas supply shortage in the short or medium term would seem to be remote:

- Most pipeline gas and LNG contracts are long-term contracts. Gas prices are typically fixed for 30 years in pipeline gas contracts and 25 years in LNG contracts.
- Construction of LNG terminals is booming. If all proposed LNG projects were finished on time, world LNG supply could exceed demand in the medium term.
- Gas has many substitutes for power generation, so if gas became too expensive or if its availability were interrupted, other fuels could step in to take its place.

The impact of China's gas demand on gas prices in other economies would probably be very modest. Gas imports of 10 Bcm to 80 Bcm per annum would be adding just 0.3 percent to 2.0 percent to projected world gas demand of 3,923 Bcm (3531 Mtoe) in 2020.[110] The supply elasticity of gas for China is virtually impossible to estimate directly, both because little gas is imported today and because most of China's potential suppliers have state-owned gas industries whose cost structure is little known. But a rough inference may be drawn from gas supply in North America, whose gas market may become more linked with that elsewhere as the United States begins to import more LNG. Recent projections by the Energy Information Administration imply a 2020 elasticity of supply of about 0.7 to 1.1, as shown in Table 62. Taking 0.9 as the midpoint, the inverse of the implied elasticity, or ratio of price change to supply change, would be about 1.1. In that case, China's gas use per ERI's projections would add at most 2.2 percent to gas prices in 2020.

Table 62 Implied Supply Elasticities of North American Gas Price in Recent Studies

Projection	Gas Price	Gas Supply	Price Change	Supply Change	Elasticity	1/ Elasticity
EIA 2010 low	$3.38	25.07 Tcf				
EIA 2010 mid	$3.49	26.09 Tcf	3.3 %	4.1 %	1.25	0.80
EIA 2010 high	$3.70	27.15 Tcf	6.0 %	4.1 %	0.68	1.48
EIA 2020 low	$4.04	27.94 Tcf				
EIA 2020 mid	$4.35	30.36 Tcf	7.7 %	8.7 %	1.13	0.89
EIA 2020 high	$4.78	32.46 Tcf	9.9 %	6.9 %	0.70	1.43

Source: APERC calculations based on EIA (2004b). Prices are in 2002 dollars.

CHINA'S POWER SECTOR AND COAL MARKETS

The calculations performed in Table 59 above can be used to estimate the incremental coal demand from expanding electricity production, as well as the associated fuel bill. First, existing coal-fired generation is netted out to find incremental generation; 1,064 TWh (1,064 billion kWh) of electricity was generated from coal in 2000.[111] The incremental generation is then multiplied by a heat rate of 9,478 Btu/kWh (0.009478 MBtu/kWh) for new coal-fired powerplants with sulphur dioxide scrubbers, assumed 36 percent efficient. The product is then divided by the heat content of coal, 21.82 MBtu per tonne, to arrive at billion tonnes of growth in annual coal demand between 2000 and 2020. This incremental demand, in turn, can be multiplied by the cost of coal in dollars per tonne to arrive at the associated increase in annual fuel costs from new coal-fired powerplants.

[110] IEA (2002b), page 410.

[111] IEEJ (2003) indicates 1355.6 TWh of generation in 2000, of which 1,115.6 TWh was thermal generation. Zhang (2004) indicates that coal accounts fro 95.38 percent of thermal generation, which would then amount to 1,064 TWh.

Table 63 shows the increase in annual coal demand and fuel costs resulting from expanding electricity production between 2000 and 2020, according to each of the scenarios outlined above:

- In the ERI scenarios, yearly coal demand grows 390 Mt to 715 Mt, depending on how much new hydro and nuclear capacity is installed. With average coal costs of $25.30 per tonne, this would mean $9.9 billion to $18.1 billion in extra yearly bills.
- In APERC's scenario, annual coal demand grows 310 Mt, and China's yearly coal bill increases by $7.8 billion under average cost assumptions.
- In Tsinghua University's scenario, with rapid expansion of gas-fired generating capacity, growth in yearly coal use is much less, just 132 Mt, so the yearly coal bill would increase just $3.3 billion under average cost assumptions.

Table 63 Incremental Coal Demand from Electricity Generation in China, 2000-2020

Indicator	ERI Scenario A	ERI Scenario B	ERI Scenario C	APERC Scenario	Tsinghua Scenario
Incremental Coal Generation	1,646 TWh	1,401 TWh	899 TWh	713 TWh	304 TWh
Incremental Coal Demand	715 Mt	608 Mt	390 Mt	310 Mt	132 Mt
Added Cost at $25.30/tonne	$18.1 billion	$15.4 billion	$9.9 billion	$7.8 billion	$3.3 billion

Source: APERC calculations based on Zhou, D. (2003), APERC (2002b), Guo (2003).

If coal demand rises as most projections indicate, China may quickly evolve from being self-sufficient in coal supply to becoming a major coal importer. According to the State Economic and Trade Commission, only about one-fifth of China's 390 coal mining townships retain long term production potential. Many coal mines, including some very large ones, have closed in recent years. Thus, investment analysts have suggested that China could become a coal importer by 2005.[112]

The increment of 132 Mt to 715 Mt in China's coal demand seen in the table would represent roughly 3 to 15 percent of world coal production today.[113] Such a sizeable increment could well place upward pressure on coal prices elsewhere, especially where rapid demand growth leads to temporary transportation bottlenecks in the ports of major coal-exporting economies, as recently seen in Australia.[114] It would also mean higher coal prices for many powerplants in China, due to the need to transport coal from greater distances. But given the vast coal reserves that remain in Australia and the United States, where coal costs have steadily declined with rising productive efficiency, coal prices in other APEC economies would not necessarily rise from today's levels.[115]

ENVIRONMENTAL IMPACTS OF ELECTRICITY GENERATION IN CHINA

Table 64 shows typical emissions of carbon dioxide, sulphur dioxide and nitrogen oxides from typical coal-fired, oil-fired, gas-fired and nuclear power plants, per gigawatt-hour of electricity generated.[116] These can be multiplied by projected amounts of generation in Table 59 to arrive at estimates of the atmospheric emissions of these gases from electricity generation in China under various scenario assumptions. Table 65 indicates the carbon dioxide emissions in various cases, while Table 66 shows projected sulphur dioxide emissions and Table 67 shows projected nitrogen oxide emissions from electric power plant operations in China in 2020.

[112] *The Economist* (2003), quoting SETC minister Li Rongrong and UBS Warburg analyst Joe Zhang, for example.

[113] EIA (2003), page 187, shows 2001 world coal demand of 5,263 million short tonnes or 4,776 million metric tonnes.

[114] Delays in coal loading and shipping, combined with reduced Chinese coal exports and rising Asian coal demand, were already leading to sharply increased prices for Australian coal in 2004. Reuters (2004) notes that the coal price in year-long contracts with Japan could rise by more than half from $26.50 per tonne from April 2003 to $40 or $43 per tonne from April 2004. Macdonald-Smith (2004) cites estimates by UBS bank of a 42 percent price increase for steam coal.

[115] IEA (2002d) notes that coal mine productivity in the United States has improved 6.7 percent annually since 1979, and that the price of coal to US electricity generators is projected to decline by 1.3 percent annually through 2020.

[116] Emissions factors from Korea Gas Corporation (KOGAS) cited in Yoon and others (2003) and from Freund (2002).

Table 64 Environmental Emissions per Gigawatt-Hour by Type of Powerplant

Type of Impact	Coal	Oil	LNG	Nuclear
Global Warming (kg CO_2): Old Plants				
Global Warming (kg CO_2): New Plants				
Acidification (kg SOx)				
Acidification (kg NOx)				

Source: Korea Gas Corporation for oil and nuclear plants and existing coal and gas plants. Freund (2002) for new coal-fired plants with scrubbers (assumed 36 percent efficient) and new combined cycle gas-fired plants (50 percent efficient).

Table 65 Carbon Dioxide Emissions from Electricity in China in 2020, Billion Tonnes

Powerplant Type	ERI Scenario A	ERI Scenario B	ERI Scenario C	APERC Scenario	Tsinghua Scenario
Coal-Fired	2,432 Bt	2,216 Bt	1,774 Bt	1,611 Bt	1,251 Bt
Gas-Fired	32 Bt	59 Bt	78 Bt	98 Bt	192 Bt
Oil-Fired	8 Bt	8 Bt	8 Bt	34 Bt	2 Bt
Nuclear	0 Bt	0 Bt	0 Bt	0 Bt	0 Bt
Total	**2,472 Bt**	**2,283 Bt**	**1,859 Bt**	**1,742 Bt**	**1,445 Bt**

Table 66 Sulphur Dioxide Emissions from Electricity in China in 2020, Million Tonnes

Powerplant Type	ERI Scenario A	ERI Scenario B	ERI Scenario C	APERC Scenario	Tsinghua Scenario
Coal-Fired	7,778 Mt	7,074 Mt	5,633 Mt	5,101 Mt	3,926 Mt
Gas-Fired	208 Mt	389 Mt	520 Mt	655 Mt	1,300 Mt
Oil-Fired	5 Mt	5 Mt	4 Mt	19 Mt	1 Mt
Nuclear	1 Mt	1 Mt	1 Mt	1 Mt	0 Mt
Total	**7,991 Mt**	**7,469 Mt**	**6,158 Mt**	**5,775 Mt**	**5,228 Mt**

Table 67 Nitrogen Oxide Emissions from Electricity in China in 2020, Million Tonnes

Powerplant Type	ERI Scenario A	ERI Scenario B	ERI Scenario C	APERC Scenario	Tsinghua Scenario
Coal-Fired	3,604 Mt	3,278 Mt	2,610 Mt	2,364 Mt	1,819 Mt
Gas-Fired	125 Mt	235 Mt	313 Mt	395 Mt	784 Mt
Oil-Fired	0 Mt	0 Mt	0 Mt	0 Mt	0 Mt
Nuclear	0 Mt	0 Mt	1 Mt	0 Mt	0 Mt
Total	**3,730 Mt**	**3,514 Mt**	**2,924 Mt**	**2,759 Mt**	**2,604 Mt**

The tables show clear environmental benefits from enhanced use of hydro and gas-fired power, as well as from slower growth in overall electricity generating requirements:

- In moving from ERI scenarios A to B to C, with the hydro share increasing from 18.6 percent to 21.6 percent to 26.6 percent, annual carbon dioxide emissions fall 25 percent from 2,472 Bt to 2,283 Bt to 1,859 Bt, sulphur dioxide emissions decline 23 percent from 7,991 Mt to 7,469 Mt to 6,158 Mt, and nitrogen oxide emissions fall 22 percent from 3,730 Mt to 3,514 Mt to 2,924 Mt, even though total projected 2020 electricity generation declines by just 8 percent.
- Tsinghua's scenario, with 28 percent less generation than ERI scenario C and 21 percent of generation fuelled by gas, has 22 percent less carbon dioxide, 15 percent less sulphur dioxide, and 11 percent less nitrogen oxide emissions than scenario C, even though Tsinghua assumes smaller shares of hydro and nuclear power.

REFERENCES

GENERAL REFERENCES

APEC Energy Working Group (2002). *APEC Energy Statistics 2000.* Tokyo.

APERC (2000). *Natural Gas Infrastructure Development in Northeast Asia.* Tokyo.

APERC (2001). *Energy Supply Infrastructure Development in the APEC Region.* Tokyo.

APERC (2002a). *APEC Energy Overview 2002.* Tokyo.

BP (2003). *BP Statistical Review of World Energy.* Website: www.bp.com/centres/energy.

IEA – International Energy Agency (1994). *Natural Gas Transportation: Organisation and Regulation.* Paris.

IEA – International Energy Agency (1996). *Asia Gas Study.* Paris.

IEA – International Energy Agency (1998). *World Energy Outlook 1998.* Paris

IEA – International Energy Agency (1999). *South East Asia Gas Study.* Paris.

IEA – International Energy Agency (1999, 2000, 2001, 2002). *Electricity Information.* Paris.

IEA – International Energy Agency (2000). *World Energy Outlook 2000.* Paris.

IEA – International Energy Agency (2002a). *Developing China's Natural Gas Market.* Paris.

IEA – International Energy Agency (2003a). *World Energy Investment Outlook.* Paris.

IEA – International Energy Agency (2003b). *Natural Gas Information 2003.* Paris.

IEEJ – The Institute of Energy Economics, Japan (2003). *Handbook of Energy & Economic Statistics in Japan.* Tokyo.

Zhou, Dadi and others, editors (2003). *China's Sustainable Energy Scenarios in 2020.* (In Chinese.) China Environmental Science Press.

ENERGY IN CHINA TODAY

APERC (2003). *Energy Investment Outlook for the APEC Region.* Tokyo.

Chen, Hanhui (2003). "LNG Changes Energy Situation in Guangdong." (In Chinese.) *South Daily.* 23 September 2003. Website: http://finance.sina.com.cn/roll/20030923/1031456296shtml.

Huang, Ju (2004). *Speed up Railway Development and Secure National Economy.* (In Chinese.) Trade & Foreign Investment Website: www.investchina.com.cn.

IEA – International Energy Agency (2003c). *Power Generation Investment in Electricity Market.* Paris. Website: www.iea.org.

IEA – International Energy Agency IEA (2003d). *Oil Market Report.* Various issues. Website: http://oerpublic.iea.org.

Mi, Ligong (2003). "Developing Together." (In Chinese.) *People's Liberation Daily.* 25 October 2003. Website: http://jczs.sina.com.cn/2003-10-25/157958.html.

MOC – Ministry of Communications of The People's Republic of China (2001). *China Transportation Development Planning.* (In Chinese.) Website: www.moc.gov.cn.

Qiu, Gang (2003). "Guangdong LNG Construction Starts." (In Chinese.) *Shenzhen Special Development Zone Daily.* 24 September 2003. Website: http://news.sina.com.cn/s/2003-09-24/0624807673s.shtml.

Shi, Lishan (2004). "500 Billion Yuan for Alternative Energy Development in the Next Fifteen Years in China". (In Chinese.) China Energy Information Network Website: www.energy-china.com/energy/ news/zhyw/31086.html.

UPI – United Press International (2003). "China's Oil Imports Are Booming". Website: www.clari.net.

Yang, Jieshi (2003). Speech at Ministerial Discussion of Carbon Sequestration Leadership Forum, 23-25 June 2003, Washington DC.

CHINA'S ENERGY FUTURE

APERC (2002b). *APEC Energy Demand and Supply Outlook 2002*. Tokyo.

EIA – Energy Information Administration (2003). *International Energy Outlook 2003*. Website: www.eia.doe.gov/oiaf/ieo/index.

Guo, Baolei (2003). *Scenario Analysis of China Energy Future*. (In Chinese.) Tsinghua University.

IEA – International Energy Agency (2002b). *World Energy Outlook 2002*. Paris.

Sinton, Jonathan and Ku, Jean (2000). *Energy and Carbon Scenarios for China: Review of Previous Studies and Issues for Future Work*. Website: www.lbl.gov.

TRANSPORTATION AND OIL

3E – 3E Information Development & Consultants (2002). *Chinese Oil Market Monthly*. April 2002

3E – 3E Information Development & Consultants (2003). *Chinese Oil Market Monthly*. May 2003.

AMR – Academy of Macroeconomic Research (2002*). China Oil Consumption Strategy Research*. (In Chinese.) Website: www.china5e.com/dissertation/naturalgas/20021220131854.html.

APEC Energy Working Group (2003). *APEC Energy Overview 2003*. Tokyo.

Asia Pulse (2004). "Public Transport to Be Key Focus for China Over Next 5 Years." 20 May 2004.

Cannon, James S. (1998). *China at the Crossroads*. INFORM Special Report, Vol. 5, No. 2.

China Daily (2001). "Oil Stockpile Target May Be Revised." Issue of 3 September 2001.

CEC – China Electricity Council (2000). *Fuel Oil Consumption and Oil Use for Power Industry*. (In Chinese.) Website: www.china5e.com.

CERS – China Energy Research Society (2002). *Energy Policy Research 2002.1*. (In Chinese.)

CPCC – China Petrochemical Consultant Company (2003). *China Petroleum and Petrochemical Industry Economics Research Annual Report 2003*. (In Chinese.)

CTA – China Transportation Association (2000). *Yearbook of China Transportation and Communications 1986-2000*.

CTA – China Transportation Association (2001). *Yearbook of China Transportation and Communications 2001*.

CTA -- China Transportation Association (2003). *Yearbook of China Transportation and Communications 2003*.

Dai, Lin (2002). "Analysis of Competitiveness of Refinery and Petrochemical Industry in China." (In Chinese.) *International Petroleum Economics,* Vol. 10, No. 5 (11 March 2002), pages 24-29.

Deng, Yusong (2004). *Analysis of China Oil Pricing Trends*. 2004 China Oil and Gas Development Forum, Shanghai, March 2004.

DRC – Development Research Centre of the State Council of the People's Republic of China (2003). *National Energy Strategic Scenarios*. (In Chinese). Website: http://news.sina.com.cn/o/2003-11-16/03351126708s.shtml.

DRC – Development Research Centre of the State Council of the People's Republic of China (2001). *Background Report: Vehicle Fuel Economy in China*. Website: www.efchina.org.

EIA – Energy Information Administration (2004a). *International Energy Outlook 2004*. Website: www.eia.doe.gov/oiaf/ieo/index.

Feng, Fei (2004). *Oil Supply and Security*. China Oil & Gas Development Forum, Shanghai, March 2004.

GII – Global Insight, Inc. (2002). *Oil Market Outlook: Long-Term Focus*. Spring/Summer 2002. Lexington, Massachusetts, United States.

IANGV - International Association for Natural Gas Vehicles (2004). *Latest International NGV Statistics*. Website: www.iangv.org.

IEA – International Energy Agency (2002c). Press release: "IEA Team in China to Promote Co-Operation for Improving Global Oil Security." Paris.

IPE – International Petroleum Economics (2003). "2002 Monthly Output of Main Petroleum Products in China." (In Chinese.) *International Petroleum Economics*, Vol. 11, No. 2, page 53.

Ito, Kokichi (2004). *Asia/World Energy Outlook*. 385th Forum on Research Works, Tokyo, 10 March 2004. The Institute of Energy Economics, Japan.

Jiang, Zemin (2002). *Build a Well-Off Society in an All-Round Way and Create a New Situation in Building Socialism with Chinese Characteristics*. Report to the Sixteenth National Congress of the Communist Party of China. Website: www.idcpc.org.cn.

JPCE – Japan Petrochemical Industry Association (2003). *Petrochemical Industry Profile 2003*. (In Japanese.)

Li, Jing and others (2003). "Impacts of Our Automobile Industry Development on Demand for Petroleum and Petrochemical Products." (In Chinese.) *Petroleum & Petrochemicals Today*, Vol. 11, No. 1.

Liu, Keyu (2002). *Issues of Oil Supply Security in China*. IEEJ Internal Seminar, Tokyo, December 2002.

Marcus, George et al. (1999): *China and Long-range Asia Energy Security: An Analysis of the Political, Economic and Technological Factors Shaping Asian Energy Markets*. Website: www.rice.edu.

NBS – National Bureau of Statistics (1993). *China Statistical Yearbook 1993*.

NBS – National Bureau of Statistics (1995). *China Statistical Yearbook 1995*.

NBS – National Bureau of Statistics (1998). *China Energy Statistical Yearbook 1991-1996*

NBS – National Bureau of Statistics (2001). *China Energy Statistical Yearbook 1997-1999*.

NBS – National Bureau of Statistics (2002). *China Statistical Yearbook 2002*.

NBS – National Bureau of Statistics (2003a). *China Statistical Abstract 2003*.

NBS – National Bureau of Statistics (2003b). *China Statistical Yearbook 2003*.

PIRA – Petroleum Industry Research Associates (2002). *Client Seminar*. New York, October 2002.

Qian, Pingfan (2003). *Main Six Barriers for Cars Entering Households*. (In Chinese.) China Auto Industry Information Network. Website: www.autoinfo.goc.cn.

Qiu, Baoxing (2004). National Urban Public Transportation Conference, Beijing, 19 May 2004.

Schipper, Lee and others (1999). *Rapid Motorisation in the Largest Countries in Asia: Implication for Oil, Carbon Dioxide and Transportation*. International Energy Agency. Website: www.iea.org.

Shen, Wenmin (2003). "Expenditure for Purchasing and Maintaining Cars." (In Chinese.) *Eastern News*. 11 June 2003.

Sinopec (2002). *Sinopec in 2001*. Website: www.sinopec.com.cn.

Sinton, Jonathan E.; Fridley, David G.; Levine, Mark D.; Yang Fuqiang, Jiang Zhenping, Zhuang Xing, Jiang Kejun, and Liu Xiaofeng (1996). *China Energy Databook*. Lawrence Berkeley Laboratory Report LBL-32822 Rev. 4.

Sinton, J and Fridley, D. (2002). "Guide to China's Energy Statistics." *The Journal of Energy Literature,* Vol. 8, No. 1.

SETC – State Economic and Trade Commission (2001). *Tenth Five-Year Plan of Fuel Oil Conservation and Substitution.* (In Chinese.) Website: www.setc.gov.cn.

SETC – State Economic and Trade Commission (2002a). *Automobile Industry 10th Five-Year Plan.* (In Chinese.) Website: www.setc.gov.cn.

SETC – State Economic and Trade Commission (2003a). *Announcement of Submitting Fuel Economy Data.* (In Chinese.) Website: www.setc.gov.cn.

Tian, Chunrong (2003). "2002 China Oil Import and Export Analysis." (In Chinese.) *International Petroleum Economics*, Vol. 11, No. 3.

Weihai Statistical Information Network (2004). "Transportation and Communication". (In Chinese.) Website: http://61.133.119.242/common/tjzd/zw012.htm.

Weisbrod, Roberta E., (1999). "Solving China's Urban Crisis: China's Transportation Energy Future." *Journal of Urban Technology*, Vol. 6, No. 1, pages 89-100.

Wonacott, Peter and others (2003). "China's Growing Thirst For Oil Is Reshaping Global Energy Market." *The Asia Wall Street Journal,* December 3, 2003.

Yang, Shangming (2003). "Optimisation of Oil Resources in China." (In Chinese.) *International Petroleum Economics,* Vol. 11, No. 3, pages 42-46.

Yu, Yuanyan (2002). *International Oil Price Risk Discussion.* (In Chinese.) China Energy Network. Website: www.china5e.com/dissertation/natural gas/20021220135012.html.

Zhang, Xuefei (2004). *Refinery Industry Indicators.* (In Chinese.) Website: http://finance.sina.com.cn /roll/2004213/1451630679.shtml.

ELECTRIC POWER GENERATION

Chang, Zhipeng (2003). *Re-pricing West-to East Gas.* (In Chinese.) Website: http://news. sina.com.cn/c/2003-09-17.

Chen, Hanhui (2003). "LNG Changes Energy Picture in Guangdong." *South Daily.* 23 September 2003. Website: http://finance.sina.com.cn/roll/20030923/1031456296.shtml

Chen, Ting (2003). *Story of Four Nuclear Power Plants.* (In Chinese.) Website: www.threegorgesprobe.org.

Chen, Ting (2004). *Start to Build 144 Power Plants This Year.* (In Chinese.) Website: http://finance. sina.com.cn.

China Energy Network (2003a). *Ordering Gas Turbine Efficiency.* (In Chinese.) Website: www. china5e.com/gasturbine/.

China Energy Network (2003b). *Turnkey Cost of CCGT.* (In Chinese.) Website: www. china5e.com/gasturbine/.

Cui, Jianchou and others (2003). *Technical and Economic Analysis of Natural Gas for Power Generation.* (In Chinese.) China Energy Network. Website: www.china5e.com.

EIA – Energy Information Administration (2004b). *Annual Energy Outlook 2004.* Website: www.eia.doe.gov.

Freund, Paul (2002). "Reducing Greenhouse Gas Emissions by Capture and Storage of CO_2." *Proceedings of the World Energy Council Tokyo Regional Symposium*, 27 November 2002, pages 110-120.

Gao, Shixian (2003). *China Power Demand Forecasting and Environmental Protection in Power Industry.* (In Chinese.) IEEJ Internal Seminar, Tokyo, 24 February 2003.

He, Yuping (2003). "System Optimization of Large-scale Natural Gas-fired Combined Cycle Power Plant." (In Chinese.) *Electric Power,* Vol. 36, No. 10.

Hitachi Engineering Co., Ltd (2003). *China Information on Power Sector.* (In Japanese.) Website: www. Chinawave.co.jp.

Huntington, Hillard G. (2002). *EMF 20 Study Design: Natural Gas, Fuel Diversity and North American Energy Markets.* Stanford Energy Modeling Forum. Stanford, California, United States.

IEA – International Energy Agency (2002d). *Energy Policies of IEA Countries: The United States 2002 Review.* Paris.

IEA – International Energy Agency (2003e). *Natural Gas Information 2003.* Paris.

Jia Wen-rui, Xu Ging, Wang Yan-ling, Zhang Jian-min and Zhang Long-yang (2002). *21 Century Energy, Environment and Oil Industry Development in China.* (In Chinese.) Oil Industry Publisher, Beijing.

Ku Jean (2004). *Renewable Energy in China: Status and Prospects.* APERC Annual Conference, 25-26 February 2004, Tokyo.

Li, Zhidong (2003). *Present Situation and Mid- to Long-Term Outlook of Nuclear Power Development in China.* Institute of Energy Economics, Japan. Website: www.ieej.or.jp.

Liu, P. (2003). *New Pollutant Emission Charging Effected July 1st.* (In Chinese.) Website: www.cq.xinhuanet.com/business/2003-07/08/content_681796.htm.

Logan, Jeffrey and Luo, Dongkun (1999a). *Natural Gas and China's Environment.* Website: www.globalchange.umd.edu.

Logan, Jeffrey (1999b). *Electrical Power Options in Developing Countries: Case Studies from China, India, and Korea.* Pacific Northwest Laboratory. Website: www.pnl.gov.

Macdonald-Smith (2004). "Coal Exports Get Caught in Shipping Traffic Jam." *The Age.* 10 February.

NDRC – National Development and Reform Commission (2004). *Power Construction Project Announcement.* (In Chinese.) Website: www.ndrc.gov.cn.

Reuters (2004). "Australia Study Sees Fast-Rising Coal Prices." 21 March 2004.

Schneider, Karen (2003). *Natural Gas in Eastern China.* APERC Mid Year Workshop, Tokyo, 29-30 October 2003.

Shi, Chang (2003). *Growing Limitation on Economic Development by Energy Bottlenecks.* (In Chinese.) Website: http://finance.sina.com.cn/g/20031209/0814552933.shtml.

SETC – State Economic and Trade Commission (2002b). *Power Industry Tenth-Five-Year Plan.* (In Chinese.) Website: www.setc.gov.cn.

SETC – State Economic and Trade Commission (2003b). *2002 Power Generation Statistical Report.* (In Chinese.) Website: www.drccu.gov.cn.

SEPA – State Environmental Protection Administration of China (2003). *Regulations of Pollutant Emission Charging.* (In Chinese.) Website: www.sepa.gov.cn.

SP – State Power (2000). *Power Source Projects under Construction 2000.* Website: www.sp-china.com.

SP – State Power (2001). *Generating Units Commissioned in 2001.* Website: www.sp-china.com.

SP – State Power (2002). *Commissioning Projects Schedule of SP in 2002.* Website: www.sp-china.com.

SPIN – State Power Information Network (2004). (In Chinese.) *Projects Under Construction.* Website: www.sp.com.cn.

The Economist (2003). "China's Coal Reserves: Tonnes of Problems." Issue of 19 April 2003.

Tianjin Coal Association Network (2003). *Price Components of Coal Shipped by Railways from Shanxi.* (In Chinese.) Website: www.tjcoala.com.

Wang, Chenpo (2004). *Nuclear Power Stays in National Power Industry Planning.* (In Chinese.) Website: http://news.sina.com.cn/c/2004-01-05/09591507993s.shtml.

Yan, Changle and others (2003). *China's Energy Development Report 2003*. (In Chinese.) Beijing.

Yoon, Jae-young; Kim, Ho-yong and Park, Dong-wook (2003). *Environmental Impacts and Benefits of Regional Power Grid Interconnections for the Republic of Korea.* Third Workshop on Power Grid Interconnection in Northeast Asia, Vladivostok, Russia, 30 September – 3 October 2003.

Zhang, Zhenming and others (2002). *Renewable Energy Development in China: The Potential and the Challenges.* Energy Foundation. Website: www.efchina.org.

Zhou, Yonggang (2003). *Price Conflict between Coal and Power Industries.* (In Chinese.) Website: http://finance.sina.com.cn/b/20030523/1109343967.shtml.