China's Electric Power Options:

An Analysis of Economic and Environmental Costs

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Table of Contents

ACKNOWLEDGMENTS I

TABLE OF CONTENTS........ III

EXECUTIVE SUMMARY........ V

MAP OF SEVEN REGIONS USED IN THE STUDY........ XI

1. INTRODUCTION 1

2. CHINA'S ELECTRIC POWER SECTOR 5

ELECTRIC POWER PRODUCTION 5
ELECTRIC POWER CONSUMPTION 7
THE ELECTRIC POWER PRICING SYSTEM........ 10
REFORM IN THE ELECTRIC POWER INDUSTRY........ 12
ENVIRONMENTAL PROTECTION AND THE ELECTRIC POWER INDUSTRY 13
FOREIGN INVESTMENT AND MARKET BARRIERS 19

3. ELECTRICITY DEMAND PROJECTION 21

REGIONAL DISAGGREGATION USED IN THE STUDY........ 21
SOCIOECONOMIC BASELINES........ 23
REGIONAL PROJECTIONS........ 26

4. POWER SECTOR TECHNOLOGY ASSESSMENTS 29

SOURCES OF ENERGY FOR POWER GENERATION 29
ENVIRONMENTAL POLLUTION CONTROL TECHNOLOGIES 33
COAL-BASED POWER GENERATION TECHNOLOGIES........ 35
NATURAL GAS AND PETROLEUM-FIRED POWER GENERATION TECHNOLOGIES........ 38
NUCLEAR POWER GENERATING TECHNOLOGIES 43
RENEWABLE ENERGY POWER GENERATING TECHNOLOGIES 44

5. MODELING LEAST-COST POWER GENERATION 47

THE LINEAR-OPTIMIZATION MODEL........ 47
MODELING ENERGY FLOWS 47
OPTIMIZATION ROUTINE 49
BASIC INPUT DATA........ 49

6. LEAST-COST ANALYSIS........ 59

BASIC ASSUMPTIONS 59
BASELINE SCENARIO 60
SULFUR DIOXIDE CONTROL SCENARIO 63
CARBON DIOXIDE CONTROL SCENARIO 68
NATURAL GAS POLICY SCENARIO 71
ACCELERATED TECHNOLOGY SCENARIO 74
COMPARATIVE COSTS........ 78

7. CONCLUSIONS & POLICY RECOMMENDATIONS........ 81

8. ENDNOTES........ 87

APPENDICES........ A-1

Executive Summary

China now ranks as the world's second largest energy consumer. The country's heavy reliance on coal causes severe pollution in many regions. Acid rain affects up to 40 percent of China's land area and causes over $13 billion in damage to forests, farms and health each year.[1] Millions of premature deaths and illnesses could be avoided each year if China met its class 2 air quality pollution standards.[2] Carbon dioxide emissions will surpass those of even the United States within the next few decades. Still, per capita energy use will remain far below that in more developed countries.

We prepared this analysis to define least-cost electric power and environmental options for China.[3] Because the power sector currently consumes over one-third of the country's nearly 1.4 billion tons of annual coal use, it is critical to focus on alternative development scenarios.

This study had three primary goals:

- assess the current and future state of power generation technologies in China
- forecast regional electricity demand through 2020 and determine the least-cost combination of technologies to meet this demand under a variety of scenarios
- recommend policies that could minimize both economic and environmental costs.

Our analysis divided China into seven regions (see map on page xi) and projected power demand for each region at five-year intervals through the year 2020. A linear programming model was used to evaluate energy sources, economic conditions, environmental constraints, and energy import and export potential for each region. The model estimated the least-cost combination of power supply and pollution control technologies needed to meet projected electric power demand. Scenarios were run to model the effects of controlling sulfur and carbon dioxide emissions, accelerating technology development, and changing natural gas prices.

Model results show that China can meet both its economic and environmental goals by applying new technologies. Scrubbers and precipitators can make coal, the dominant fuel, more acceptable. Surprisingly, natural gas, renewable energy, and advanced power generation technologies could substantially reduce capital, fuel, and environmental costs in certain regions of the country.

China plans over the next two decades to adopt, produce, and market advanced power generation technologies. Technology alone will not solve power or environmental problems. However, combining technology with legislation to limit sulfur emissions, policies to give greater incentives to natural gas producers, and training to improve management skills, China can improve its ability to meet its goals for economic development and environmental protection. We assessed power generation technologies that could play a significant role in meeting the nation’s future demand and present the findings after the section on results and recommendations.

Results and Recommendations

We conclude that it is cheaper to control sulfur and particulate emissions in southern China than to incur the environmental and health costs they cause. Moreover, technical systems are available that are affordable, even in China. Promising solutions include sulfur scrubbing, integrated gasification combined cycle (IGCC) power plants, and natural gas. A summary of specific conclusions and recommendations follows. For more information on our recommendations and conclusions, see Section 7.

Power demand will increase four-fold by 2020: China's power demand will reach 4,000 terawatt-hours (TWh) by 2020, a four-fold increase from 1995 consumption.

Pollution is expensive: Acid rain, with sulfur dioxide as its main precursor, causes over $13 billion per year in damages to human health, agriculture, and materials. Combined with other pollutants, such as particulates and nitrogen oxides, air pollution alone causes millions of premature deaths and illnesses in China each year.

China has made impressive progress in energy conservation: China deserves recognition for its unprecedented success in energy conservation since the late 1970s. The government has held energy elasticity at or below 0.5, meaning that the economy is growing twice as quickly as energy consumption. If China had not reduced energy consumption, the country would now be consuming about twice as much energy as it actually does and emitting twice as much carbon into the atmosphere.

Controlling sulfur emissions is a priority: Uncontrolled sulfur emissions represent an urgent environmental and economic problem in China, especially in the south. This study concludes that installing sulfur control equipment on new plants in the south and east would be cheaper than incurring the health and environmental costs of uncontrolled emissions. Initiating a sulfur permit or stricter tax system may be the cheapest way to cut growth in future emissions.

Nuclear power is not competitive: Nuclear power is not competitive with the electric power options considered in this study. Our cost estimates, based on recent experience in China and industry projections of future price decreases, indicate that nuclear power is at least 70 percent more than coal plants using scrubbers in the baseline scenario. (See Summary Table 1.) In an advanced technology scenario where nuclear capital costs were assumed to drop to $1,210 per kilowatt, discounted electricity costs were still 45 percent higher than power generated from natural gas combined cycle units.

Hydropower is costly: Large-scale hydroelectric plants appear uneconomical in this study because of high capital investment costs. The model, however, does not consider separately the capital costs related to power generation and those associated with parallel objectives, such as flood control and improved navigation, so these plants are not accurately valued in the linear programming model. Negative environmental externalities, such as silting, ecosystem shock, and loss of antiquities, were also not considered. It is unlikely that hydroelectric plants would be competitive given a complete systems analysis. Small hydroelectric plants may have lower environmental impact than large plants.

Natural gas could play a major role: China could meet up to one-third of its future power generation needs with natural gas for less total cost than using coal if it begins manufacturing gas turbines domestically and develops low-cost natural gas sources. Current market conditions for natural gas in China are severely distorted. Although policy is changing, exploration and development are discouraged by low prices, biased leasing of potential fields, and perverse allocation of gas to favored industries. Foreign technology for both exploration and power generation would help change China's energy future but not without dramatic policy reform. Natural gas was largely ignored in China's past, but we believe the government should now reexamine its potential.

Summary Table 1
Levelized Costs for Electric Power Generation in Southeastern China
(U.S. cents per kilowatt-hour)

Scenario	Pulverized Coal	Coal w/ FGD	Coal w/ EE	IGCC	CCGT	Nuclear*
1998	3.7	4.2	4.7	5.2	3.9	7.2
2005 Baseline	3.8	4.3	4.7	4.4	3.7	6.1
2005 Policy	3.8	4.3	4.7	3.8	3.4	4.9

Note: FGD = Flue gas desulfurization (dry scrubbers); EE = includes environmental externality fee of $965 per ton of SO_2; IGCC = integrated gasification combined cycle; CCGT = combined cycle gas turbine; coal cost = $35 per ton for pulverized coal plants and $30 per ton for lower-grade coal in all other coal-burning plants; natural gas cost = $2.50 per gigajoule. Transmission costs not included. Discount rate = 12 percent. See Table 5.11 for other assumptions. Levelized cost analysis is described in Appendix B.
*Includes $0.00016 per kilowatt-hour sinking fund for nuclear decommissioning.

China lacks sufficient commitment to technology: The government needs to establish a more aggressive research and development (R&D) program for other advanced power generation technologies including wind turbines, fuel cells, gasification processes, and photovoltaic technologies. By learning to manufacture these technologies domestically, China can ensure greater penetration in home markets and perhaps become a leading exporter of this high-tech, high-value equipment.

Efficiency remains China's least-cost option: China's cheapest option is to continue its successful efforts to conserve energy and raise energy efficiency. Raising energy efficiency is almost always cheaper in China than adding new supply.[4]

All modeling has limitations, and this effort is no exception: Linear programming does not reproduce observable behavior found in market economies. Higher energy prices, for example, do not lead to reduced demand in linear programming models. Real-life investment decisions, furthermore, are difficult to simplify in the way that linear programming models require (they do not, for example, value risk and convenience or account for habit). Further studies of this type could take advantage of the strengths found in linear optimization models while incorporating the benefits of models such as general equilibrium models based more on observable behavior.

Market reform is China's most powerful policy tool: The Chinese government could take advantage of the current period of restructuring bureaucracies to establish an even more rational and market-based power system. Competition in the power supply sector is becoming more common in many countries because it lowers prices and allocates resources efficiently. China could also begin to consider a pathway to further competition in the generation of electric power.

Inter-regional authority remains important: Current restructuring in the government is resulting in decentralization and greater decision-making authority at the provincial and local levels. It is important for a national or interregional body to maintain responsibility for nationwide power planning so that unified and coordinated decisions can be made. Only a supraprovincial agency, for example, would be able to coordinate the decision to send power rather than coal from southwest China to Guangdong.

Summary of Policy Recommendations

- require sulfur scrubbers on new power plants in southern China
- accelerate R&D on gas and wind turbines, fuel cells, photovoltaics, gasification, and "clean coal" technologies
- continue reforms that make greater use of market forces, especially in the natural gas sector
- maintain an emphasis on efficiency as a cheaper alternative to new power supply.

Technology Assessments

Coal: Pulverized coal power technologies will continue to play a dominant role in new power generation in China through 2020 under the scenarios we explored. China can domestically manufacture 300 megawatt and smaller boiler and turbine units. This technology is relatively well developed. Current capital costs average about $600 per kilowatt without sulfur control technology, at least 30 percent less than international prices.[5] Foreign joint ventures and multilateral development banks are introducing larger units and supercritical steam technology.[6] Government policy on controlling sulfur emission will significantly affect the evolution of China's coal-based power sector. Coal-washing and flue gas desulfurization (FGD) will be required in many regions, but these extra costs will make other generation technologies more competitive.

IGCC: Chinese planners place great hopes on IGCC power plants. IGCC, which would first gasify coal then generate power with gas turbines, can reach efficiencies of 45 percent, and would emit few particulates or oxides of sulfur. IGCC could thus help China take full advantage of its plentiful coal supplies while minimizing air pollution. IGCC development in China and industrialized countries, however, has been slow. When IGCC demonstrations are complete, initial capital costs will total an estimated $1,350 per kilowatt. Final power costs would be significantly less than costs for nuclear power, but still more costly than other options. This technology would allow China to continue using inexpensive, regionally-available coal as a source of fuel.

Combined Cycle Gas Turbines: Combined cycle units operating on natural gas currently meet less than 1 percent of China's power demand, but this percentage could increase substantially if China champions the development and use of methane-rich gases. Methane, of course, is the main ingredient of natural gas. China could boost availability of natural gas by exploiting advanced exploration and extraction technologies (such as three- and four-dimensional seismic imaging) to increase domestic production, using more coal bed methane (CBM), supporting construction of pipelines to import gas from Russia and Kazakhstan, and importing liquefied natural gas (LNG) into coastal China. Until China can manufacture its own advanced combined cycle units, it must buy imported units with capital costs of about $650 per kilowatt. If China begins producing advanced gas turbines early next century and accelerates development of gas resources and infrastructure, natural gas could be very attractive in the booming coastal provinces. Gas availability and price are critical factors in making this possible. For health and environmental reasons, however, priority use of gas would first go for direct (non-electric) use in residential, commercial, and industrial applications, which currently burn coal very inefficiently.

Nuclear: China has an ambitious plan to boost nuclear power capacity along the southern and eastern coast where quality, low-cost energy supplies are insufficient. The country currently can manufacture about 70 percent of the components used in building nuclear power plants. Capital investment costs for nuclear power plants in China using imported equipment have averaged about $2,000 per kilowatt. (See Table 4.6.) In the baseline scenarios, however, we use a value of $1,810 per kilowatt by assuming that China will play a greater role in manufacturing the necessary components. With plant construction taking at least five years, the cost of nuclear power along the coastal zone is 70 percent higher than coal with desulfurization equipment. (See Summary Table 1.) We estimate that nuclear capital costs over the next decade will drop to $1,450 per kilowatt and nuclear power will cost only 40 percent more than desulfurized coal power. Under an advanced technology scenario, capital costs for nuclear power are assumed to drop to $1,200 per kilowatt, but discounted cost will still be almost 45 percent higher than power produced by combined cycle plants assuming sufficient low-cost gas is available.

Fuel Cells: Industrialized countries have made rapid advances in fuel cell technology over the past five years. They produce electricity without combustion and may thus offer cleaner power generation than other fossil fuel systems (even accounting for the production of hydrogen-rich gases from fossil fuels). Currently available phosphoric acid fuel cells are expensive, but molten carbonate and solid oxide fuel cells will enter industrialized country power markets over the next decade with more competitive prices. Proton exchange membrane (PEM) fuel cells may power hundreds of thousands of vehicles by

2005 and provide combined heat and power (CHP) to other users.[7] This set of technologies may be one of China's greatest opportunities to reduce power plant and transportation pollution, increase industrial efficiency, and expand high-tech exports. Fuel cells can operate on coal gas, natural gas, gasified biomass, or a variety of alcohols. China, however, is not sufficiently investing in research and development in these areas to take advantage of these new technologies as they become available. Even having the ability to adapt and utilize advanced foreign systems will require stronger efforts to train scientists and managers to manufacture and maintain such systems.

Wind: Most of China's quality wind sites are in Inner Mongolia, Xinjiang, and southeastern coastal regions. Current international capital costs for 750-kilowatt turbine units are about $1,000 per kilowatt. When China is capable of manufacturing large turbines domestically early next century, capital costs could fall to below $700 per kilowatt. Levelized costs under this scenario would drop about 30 percent, faster than any other policy scenario. Most Chinese and international experts believe wind will generate power economically in remote, off-grid regions in the Chinese countryside, but they doubt its ability to supply base-load electricity at competitive prices during the coming decades. Large wind farms with compressed-air, flywheel, or pumped water energy storage might be capable of supplying base-load electricity , however, in regions with high wind quality.[8]

Biomass Gasification: Technologies used to generate power using biomass as a fuel are currently being demonstrated. Systems available in China use steam turbines and operate like coal-fired units but with fewer overall environmental externalities. Gasification and pyrolysis technologies could be developed in China within 10 years that would boost overall efficiency to near 50 percent, making this technology competitive with coal in regions of plentiful biomass and expensive coal. Yet, biomass may not play a significant role in the power sector because it is hard to collect, transport, and store in large volumes, and because higher overall efficiencies can be gained by using biomass as a fuel for industrial and agricultural process heating, space heating, and cooking rather than for power generation. Modern technologies could be developed for China to allow for efficient, local power production using biomass, but neither China nor the west are investing in the technology on a scale that could affect China’s power supply over the next decade.

Map of Seven Regions Used in the Study

Region	Areas Included
Northeast	Liaoning, Jilin, Heilongjiang, eastern Inner Mongolia
North	Beijing, Tianjin, Hebei, Shanxi, western Inner Mongolia
Northwest	Shaanxi, Gansu, Ningxia, Qinghai
East	Shanghai, Jiangsu, Zhejiang, Anhui, Shandong, Fujian
Central	Henan, Hubei, Hunan, Jiangxi
Southwest	Sichuan, Chongqing, Guizhou, Yunnan, Guangxi
Guangdong	Guangdong Province

Note: The regions of Xinjiang, Tibet, Hainan, and other Chinese islands are not included in this study because of their small power demands and independent power grids.

1. Introduction

China's economy has expanded at an average rate of over 9 percent each year for the past two decades. Continuing this rapid economic growth while simultaneously implementing effective pollution control policies presents China with an urgent challenge. This study seeks to define the least-cost combination of technologies and policies for China's electric power sector, a major element of the country's economy.

China surpassed Russia in 1993 to become the second largest energy user in the world. By 1996, total primary commercial energy consumption reached 35 exajoules[9], which was more than three times the energy consumption in India, but still only about 40 percent as much as in the United States. On a per capita basis, however, the average American still consumes 12 times as much energy as the average Chinese.[10]

China’s energy sector is distinctive for its heavy reliance on coal. (See Table 1.1.) No other major economy relies so heavily on coal to meet its primary energy needs. Coal use accounts for large percentages of both industrial energy consumption and urban household energy use.

Table 1.1
The World's Largest Energy Consumers, 1996

	Coal (%)	Oil (%)	Natural Gas (%)	Hydro (%)	Nuclear (%)	Other* (%)	Total Demand (EJ)
China	*72.8*	*19.9*	*2.1*	*5.1*	*0.4*	--	*35.1*
United States	22.0	38.4	24.1	4.1	7.7	2.9	88.5
Russia	17.2	22.1	50.8	6.1	4.4	--	24.6
Japan	14.2	55.8	12.3	3.8	13.5	0.3	20.3
Germany	24.0	41.4	22.7	1.3	10.8	0.2	13.7
Canada	10.7	28.9	25.7	29.8	8.2	--	11.6
India	55.8	29.9	6.9	6.5	0.8	--	10.9

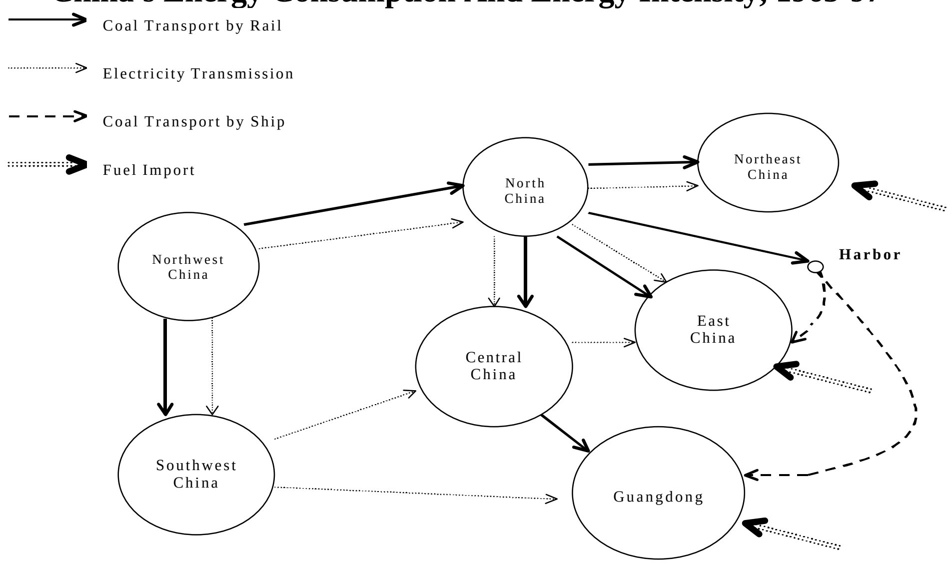
Note: EJ = Exajoule, one billion gigajoules, or, 1×10^{18} joules.
* Refers to geothermal, solar, and wind electric power consumption.
Source: 11

China now consumes almost 1.4 billion tons of coal a year, leading the world in both production and consumption. Coal has fueled much of China's economic growth over the past two decades and has been responsible for helping alleviate poverty and raise income levels. However, the environmental degradation resulting from burning this much coal--often at low efficiencies with little or no emissions control--is causing alarm both inside and outside China's borders.

Environmental problems associated with heavy reliance on coal would be even worse if China had not initiated a successful energy conservation program in the early 1980s.

China's energy elasticity--the change in energy growth divided by the change in economic growth--has been held below 0.5, indicating that incomes are rising at least twice as quickly as energy use. In other words, China has reduced its energy intensity by 4.5 percent each year over the past two decades. Most developing countries have energy elasticities closer to or above 1.0, making China's achievement unique in the developing world. Without this effort to limit energy demand, China's energy consumption could now be twice as high as it actually is, resulting in much greater environmental damage.[12] (See Figure 1.1.)

Figure 1.1
China's Energy Consumption And Energy Intensity, 1965-97



Note: Mtce = million tons of coal equivalent. Energy consumption in 1996 and 1997 are based on preliminary data.
Source: 13

China generates over three-quarters of its electricity by burning coal. Emissions of sulfur oxides, particulates, and nitrogen oxides damage human and ecosystem health, materials, and agricultural output. As the average efficiency of many of China's coal-fired power plants lags far behind Western rates, carbon emissions are also unnecessarily high.[14] Current construction of hydroelectric plants requires that large numbers of people be resettled, having many potentially negative impacts on local ecosystems. Power failures, caused by excessive demand and poor operations and maintenance practices, have resulted in huge losses in industrial production. Until China begins to internalize more of these environmental externalities and establish more integrated operational procedures, irrational development will continue to cut real economic growth.

While the energy sector as a whole grew between 3 and 5 percent each year over the past two decades, the power sector has achieved an average annual growth rate of 8 percent. Over the past decade, China has added about 15 gigawatts of new power capacity each year, equivalent to adding a new 565 megawatt power plant every two weeks. Future growth and rising incomes are expected to keep this demand rising steadily.

This report provides several recommendations to put the Chinese electric power industry on a more sustainable course while meeting the rapidly growing power needs of the country. In this study, we first project power demand by region through the year 2020. We then use a linear optimization model to determine which combination of technologies can supply this power for the lowest overall cost. We generate a baseline scenario plus several other cases related to sulfur emissions reduction. We also provide a carbon reduction scenario. Finally, we consider the effect of changing natural gas and capital costs in the power generation mix.

Section 2 describes China's electric power system, and the effect market-oriented reforms have had on it over the past 15 years. We discuss capital requirements, electricity tariffs, environmental protection, and foreign investment. Section 3 presents results from forecasting China's electricity demand through the year 2020 at five-year intervals. In this forecast, we divide the country into seven regions according to energy availability, economic conditions, and environmental situations. We compare demand projections with projections from other studies.

Section 4 assesses the types of energy sources available for power supply, ranging from coal and hydropower to natural gas, wind, solar, geothermal, and nuclear. It also assesses major power generation or environmental control technologies that could play a significant role in China's power sector by 2020. Section 5 describes the linear optimization model. The program gives modelers flexibility in estimating the least-cost combination of power sources that will meet overall demand. It allows modelers to consider a variety of constraints arising from energy supply or environmental limitations. Despite the model's flexibility, it does have limitations. In particular, the program is not a behavioral model. That is, it will not adjust total demand according to changes in energy prices or environmental conditions. However, we believe the model is a useful tool that allows researchers to explore policy options in the power and environmental sectors.

We present results from five scenarios created to analyze different policy options in Section 6. In addition to the baseline, the study includes scenarios in which sulfur dioxide emissions are capped and taxed, carbon emissions are controlled, gas prices vary, and advanced power generation technology is available at low capital costs (see box below). We provide the total costs for each scenario over the 20-year period at the end of Section 6.

Scenario	**Description**
Baseline	No environmental constraints or emission limits.
Sulfur Dioxide Control	Cap sulfur emissions and/or apply sulfur emission fees.
Carbon Dioxide Control	Cap carbon emissions at different levels.
Natural Gas Policy	Vary natural gas prices and gas technology costs.
Advanced Chinese Technology	Model accelerated technology development by lowering capital costs after 2005 and including sulfur externalities.

Section 7 provides conclusions and recommendations from the modeling.

Section 8 contains a list of endnotes referenced in the report.

Appendix A summarizes the mathematics of the least-cost optimization model and Appendix B provides a brief overview of levelized cost analysis. Appendices C, D, and E contain a list of abbreviations used in the study, a bibliography of related resources, and conversions, respectively.

2. China's Electric Power Sector

This section provides an overview of China's electric power sector. We begin with a summary of power supply and demand over the past decade. We also discuss electricity prices, power sector reform, environmental issues, and foreign direct investment.

Electric Power Production

China's electric power industry is based on low-cost, plentiful domestic energy resources and low-cost, locally made power generation technologies. Coal has been historically viewed as plentiful and cheap, and China has been able to produce some of the world's least expensive coal-fired power plants. For these reasons, coal now supplies the vast majority of electric power production.

Thermal power plants, almost all of them coal-fired, accounted for over three-quarters of China's installed capacity in 1996. (See Table 2.1.) Hydro and nuclear power provided about 23 and 1 percent of capacity, respectively.

Table 2.1
Sources of Installed Capacity and Power Generation in 1996

	Thermal	Hydropower	Nuclear	Total
Installed Capacity (GW)	178	52	2	232
Power Generation (TWh)	876	185	14	1,075

Note: GW = gigawatt, one billion watts, or, 1,000 megawatts (MW); TWh = terawatt hour, one trillion watt hours, or one billion kilowatt hours.
Sources: 15, 16

China's electric power industry has developed very quickly over the past decade. (See Table 2.2.) Total installed capacity increased from 103 gigawatts in 1987 to an estimated 250 gigawatts in 1997,[17] an average annual growth rate of over 9 percent. Installed capacity increased by about 15 gigawatts annually, the equivalent of adding a 565 megawatt plant every two weeks.

Many new power plants were relatively efficient because they were larger, reaching 300 megawatts and higher. Many smaller, inefficient plants were also added to quickly meet soaring demand. But the share of electric power produced from large-scale plants increased significantly. In 1987, only 11 plants had a capacity of 1 gigawatt or more. The combined capacity of these power plants was about 15 gigawatts, accounting for one-seventh of the nation's total. By 1994, there were 38 power plants of 1 gigawatt or more with a combined capacity of 87 gigawatts, accounting for one-third of the nation's total. The proportion of power generated from large-scale thermal power plants--defined as having unit capacity over 100 megawatts--increased from 5 percent in 1987 to 63 percent in 1995. The efficiency of thermal power generation increased from 28.6 percent to 29.8 percent during the same period.[18]

Table 2.2
Development of Chinese Electric Power Capacity and Generation, 1987-97

Year	Installed Capacity (GW)	Growth Rate (%)	Power Generation (TWh)	Growth Rate (%)
1987	103		497	
1988	116	12.2	545	9.6
1989	127	9.6	584	7.3
1990	138	8.9	621	6.3
1991	152	9.8	678	9.0
1992	167	9.9	754	11.3
1993	183	9.8	836	10.9
1994	200	9.3	928	10.9
1995	217	8.7	1,007	8.5
1996	232	6.9	1,075	6.8
1997[19]	250	7.7	1,140	6.0
Average		9.3		8.7

Sources: 20, 21, 22

The electric power supply mix also began to change during the late 1980s. In 1987, China's electric power supply consisted only of conventional coal-fired, oil-fired, and hydropower plants. In 1993, the first large-scale pumped storage hydropower station was put into operation. In 1995, hydropower stations with a total capacity of 45 gigawatts were under construction, including the massive 18 gigawatt Three Gorges Dam. Foreign investors have built several relatively small oil- and gas-fired combined cycle units in recent years, primarily along the eastern and southern coast.[23]

China also started commercial nuclear power production in 1992 with the 300 megawatt Qinshan nuclear power plant. This plant was designed, manufactured and constructed solely by Chinese specialists, although it does contain some imported components. The Daya Bay nuclear power plant, which consists of two 900 megawatt French units, was put into operation in 1994.

By 1995, China had developed 14 wind power farms with a combined capacity of 50 megawatts, while installed solar photovoltaic, geothermal, and ocean tidal power stations reached 6, 32, and 11 megawatts of capacity, respectively.[24]

The east produced more power than any other region with over 28 percent of the nation's total. The southwest generated approximately one-third of all hydroelectric power. (See Table 2.3.)

Electric Power Consumption

China had by 1995 become the world's second largest electricity consumer with total consumption of about 1,000 terawatt-hours. Electricity consumption increased at an annual rate of about 10 percent from 1991 to 1995. On a per capita basis, however, 1995 consumption was 815 kilowatt-hours, only one-third of the world average and just one-thirteenth the level in the United States.[25]

Table 2.3
Power Generation by Region in 1995 (TWh)

	Total	Hydro	Thermal
North	166	3	163
Northeast	122	13	109
East	283	24	256
Central	152	48	102
Guangdong	82	13	58
Southwest	121	62	59
Northwest	65	17	47
Total	1007	187	807

Sources: 26, 27

Sectoral Consumption

Chinese industry has been the primary electricity-consuming sector in China for many years. In 1995, industry accounted for three-quarters of total power consumption, followed by the residential sector with about 10 percent.

Electricity use in the commercial and residential sectors increased by about 16 percent each, while consumption in the agricultural sector grew only half as quickly. (See Table 2.4 for a complete picture of electricity consumption by sector.)

The elasticity of electricity consumption--defined as the rate of growth in electricity consumption divided by the rate of growth in gross domestic product (GDP)--was 0.81 from 1981-1990, and 0.83 from 1991-95. According to Chinese researchers, two primary factors kept elasticity in China low over these periods:

- A general shift away from energy-intensive heavy industries to higher value-added light industry and service sectors;

- Continued control of electricity consumption by the government in the form of quotas and higher prices when quotas are exceeded, despite China's shift from central planning to a market economy.

Researchers at Lawrence Berkeley National Laboratory, however, argue that technical efficiency improvements resulting from government policies and programs are the most important reasons for these low elasticities.[28] Other significant reasons include retirement of older equipment, introduction of more efficient plants, and possible overstatement of real GDP growth.

Table 2.4
Power Consumption by Sector

	1995		**1990-95 Annual Growth Rate**
	(TWh)	(%)	(%)
Agriculture	61	6.1	7.4
Industry	739	73.7	8.7
In which:			
Heavy Industry	148	14.8	8.3
Light Industry	590	58.9	8.8
Or			
Mining	97	9.7	7.6
Manufacturing	642	64.0	8.9
Construction	11	1.1	10.8
Transportation and Communication	18	1.8	11.4
Commercial*	57	5.7	16.5
Residential	101	10.0	15.9
National Total	1,002	100.0	10.0

Note: Rounding may produce small errors.
* Includes the so-called “nonproductive” sectors of government institutions, educational bodies, health sector institutions, and science and research institutes.
Sources: 29, 30

Regional Consumption

Guangdong and the east and southwest regions led the country in electricity consumption growth between 1990 and 1995. The northeast, struggling to reform its antiquated heavy industrial sector, increased electricity consumption by 6 percent on average over the same period. (See Table 2.5 for regional growth rates.)

Table 2.5
Power Consumption and Growth Rates by Region

	1995 (TWh)	1990-95 Annual Growth Rate (%)
North	158	9.1
Northeast	127	6.1
East	283	11.3
Central	150	9.3
Guangdong	115	18.2
Southwest	64	11.2
Northwest	79	7.5
National Total	1,002	10.0

Note: Rounding may produce small errors.
Sources: 31, 32

Electricity Supply Shortages

Power supply shortages once posed a major problem in China, but this problem has diminished with new power supplies and conservation efforts. Some regions now, in fact, face temporary oversupply problems due to a combination of slower economic growth, rapid supply expansion, and lost demand in closed factories. Supply shortages still affect many areas of the country. In most regions, the gap between peak and off-peak loads is increasing, and power supply shortages are growing more serious during peak load periods.

The regional power supply situation ranges from adequate to severe shortage:

North	Minor shortages except in southern Hebei province.
Northeast	No shortages because of slow economic development in recent years.
East	Some shortages in Shanghai and Jiangsu during peak summer periods. Serious shortages in Shandong as a result of rapid economic growth. Occasional shortages in Fujian as variations in rainfall affect hydropower.
Central	Shortages in Henan during peak loads. Hydropower problems similar to Fujian.
Southwest	Shortages in some areas of Sichuan. Hydropower problems similar to Fujian.
Northwest	Supply shortages often serious, except in Ningxia.
Guangdong	Supply adequate except for some areas in north and west.

The Electric Power Pricing System

Government policy on electricity pricing has evolved rapidly over the past decade. Power prices are now set to recover costs and provide at least some profit in many regions of the country. Power tariffs remain complex, however, and additional reforms remain to be made.

Electric Power Pricing

The central government formerly was the only investor in the electric power industry and it set prices to recover only the operational cost of generating power. The government historically subsidized the price of electricity to assist in the development of key industries and reduce the cost of living for citizens. Power tariffs for industrial enterprises and consumers provided electricity far below the cost of generation. Without sufficient income from the sale of electricity, China's electric power sector lacked funding to build new power plants and maintain old ones. A growing gap between demand and supply resulted.

China started to reform electric power pricing to alleviate these power supply shortages and promote development of the electric power industry. In 1985, realizing the need for reform, the Chinese government implemented a new policy for setting electricity tariffs on projects financed by local and foreign funds. The goal was to minimize expenditures from the central government and use market forces to encourage the development of power projects. The price of electric power from such projects was allowed to reflect the cost of financial sources. Shortly thereafter, projects funded by the central government included the cost of finance. This reformation made possible recovery of the investment required to plan, build, and operate electric power plants.

In 1988, the Chinese government imposed a fee to collect funds for developing the power industry. The fee was two Chinese fen per kilowatt-hour (100 fen equal one RMB and one RMB at the time equaled about $0.27), which was imposed on industrial consumers' electricity bills. Starting in 1996, this fee was extended to residential electricity bills. To help defray costs of building the Three Gorges Dam, the government added a fee of 0.3 fen per kilowatt-hour in 1993 and raised the fee to 0.4 fen per kilowatt-hour in 1994 and then to 0.7 fen per kilowatt-hour in 1996. The last increase applied only to consumers in economically developed regions and in the project area. Impoverished counties and counties connected only to independent local grids do not have to pay this fee.

The Chinese government implemented a "fuel cost rider" policy in 1987. Under this policy, changes in fuel costs or fuel transportation costs could be passed through in power tariffs to keep overall profit levels constant. Before this reformation, the price of electric power was fixed once the power project went into operation. Naturally, the old system increased risks for would-be investors.

The Chinese government in 1997 intensified its effort to reform electricity tariffs. Authorities adjusted rates to compensate more for changing fuel and transportation costs, and to recover loans for new power plants. They also raised prices for residential users and industries with high capacity demand. The government also reduced fees unrelated to power consumption for funding local development, education, and even birth control programs. These fees led to excessively high tariffs in some areas.

China still uses two types of tariffs: the old "instruction" prices for state-owned power plants and "guidance" prices for new power plants that use funds from other sources, though the gap between the two types is decreasing. The government hopes to unify the price of electric power within grids soon, but many obstacles remain. The government still controls prices for some residential customers, large state-owned enterprises, and agricultural consumers. Subsidies to these sectors are decreasing but have not been completely abolished, particularly for irrigation. (See Table 2.6 for historical price differences by user class.)

Table 2.6
Relative Electricity Prices by User, 1980-93
(%)

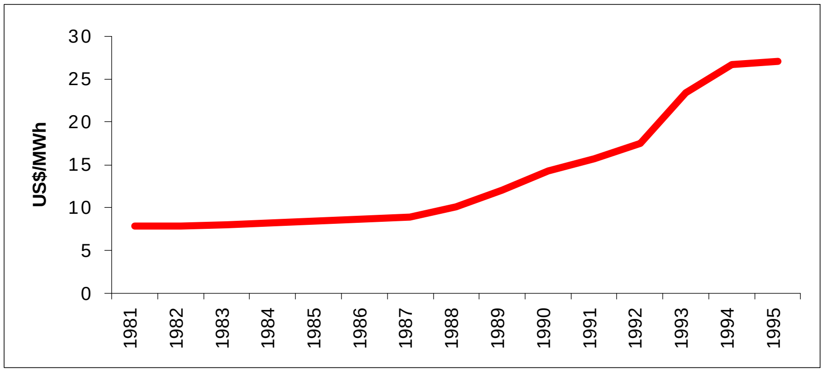
	Average	Large Industry	Small Industry/ Commercial	Agriculture	Nonhousehold Lighting	Wholesale
1980	100	96	123	83	249	71
1985	100	94	119	79	229	77
1988	100	93	111	73	193	79
1993	100	98	119	78	103	80

Source: 33

Changes in Electric Power Pricing

Electric power prices were stable before 1988. Power prices shot up by over 10 percent a year after 1988 and by over one-third in 1993. (See Figure 2.2.) On average, while comprehensive commodity prices increased 7 percent from 1981 to 1993, electric power prices rose by 9 percent.

Figure 2.1
Average Wholesale Electricity Prices in China, 1981-95



Note: Average refers to the mean value over the entire country.
Source: 34

Local Chinese administrations started to implement selective time-of-use pricing in 1985 to help reduce the gap between power supply and demand. Time-of-use pricing mainly applies to large consumers of electric power who take power at high voltage and who represent about one-third of electric power consumption. The ratio of peak load to off-peak prices is usually 3 to 1. Seasonally-adjusted pricing is also being implemented in some regions. Problems preventing wider application of time-of-use and seasonal pricing include the following:

1) basic prices are too low
2) the difference between peak and off-peak prices does not provide enough incentive to conserve energy
3) electric meters are of poor quality or too expensive
4) tariff collection is inadequate.

Reform in the Electric Power Industry

Decision-Making Under Central Planning

China's electric power industry was developed under central planning. The central government managed the industry, provided all investment funds, and received all profits from its operation. Between 1980 and 1985, 80 percent of power sector net income went to the government.

The central government has replaced direct investment--essentially grants--with loans provided through financial institutions. Power generation enterprises are expected to operate as "businesses" that repay loans and pay taxes. Therefore, the profitability of power supply enterprises has decreased. Because electric power production enterprises did not develop a reinvestment capability before the central government decreased its investments, power supply shortages became more serious in some regions. Capacity shortages reached 20 percent in the late 1980s and early 1990s.[35] Limits on power supply and frequent power outages resulted in losses in economic output of up to 25 percent.

Progress in Reforming the Electric Power Industry

Reform of the electric power industry began in the 1980s. The first change was aimed at expanding sources of investment, especially from local governments, industrial sectors, and enterprises. These new financial resources included the National Energy Investment Corporation, which represented the central government; local power industry investment agencies; large power enterprises, such as the Huaneng International Power Company, which was authorized to use foreign funds; and independent power investment enterprises such as Xinli Energy Development Company of the Zhongxin Group.

These reforms weakened the central government's monopoly of the electric power industry. Electric power was now regarded as a commodity to be bought and sold on the open market, rather than a product to be allocated by government. For new independent power plants, prices were set based on recovering investment and achieving profits. These plants were allowed to sell power to the grid competitively through established contracts.

Existing state-owned enterprises were reorganized as companies or enterprises to operate commercially in a market environment.

Reform prompted a surge in development of China's electric power industry. Capacity increased 4 to 5 gigawatts annually during the early 1980s and by approximately 15 gigawatts per year since the 1990s. Power supply shortages declined. While the central government provided two-thirds of power industry investment in 1980, other domestic and foreign sources provided 50 and 10 percent, respectively, by 1993.[36] Owners now included the state, joint state and local governments, stockholders, sole proprietors, and local and foreign enterprises. Sino-foreign joint ventures or cooperative ventures were created. Such enterprises operate independently and sell power to the grid. They make investment decisions based on their own interests. However, all projects are subject to approval by local and central planning commissions, and large projects--those costing over $30 million--must be approved by the State Council.

The central government drafted an "Electric Power Industry Law" in 1995 and enacted it in April 1996. The law is regarded as the fundamental legal framework of the electric power industry. It ensures development of the industry in a market economy. The law protects the rights and interests of investors, attempts to direct the behavior of players in the electricity market, and encourages fair competition. Supplemental regulations on power supply and transmission grid operation were also issued independently of this law.

The Chinese government established the National Electric Power Corporation in 1997, a significant step in reforming the administrative system of the electric power industry. The Ministry of Electric Power Industry was disbanded at the National People's Congress in March 1998.[37] The corporation was established by the State Council as a solely state-owned entity and is authorized to manage national assets, make investments, operate state-owned power grids, and manage transmission between grids. The corporation will act as an independent legal person to develop and compete in the market. In the future, electric power enterprises will operate more independently from the government and the power market will be more open to investors. There is some concern that the regulatory functions once carried out by the Ministry of Electric Power Industry will not be transferred to the National Electric Power Corporation.

Environmental Protection and the Electric Power Industry

China's tremendous economic growth in recent years has come at a high price to its land and its people. In almost every major city, oxides of sulfur and nitrogen as well as particulates exceed government standards, often by several hundred percent. Urban air pollution is responsible for millions of deaths and injuries each year in China. Acid rain has damaged from 10 to 40 percent of the land area, and air pollution contributes to over 7 million work-years lost each year to related sickness. Total GDP loss due to environmental pollution exceeds 8 percent.[38]

Large parts of the southwest region suffer from acid deposition due to heavy reliance on coal containing up to 5 percent sulfur. Deforestation has accelerated desertification and left once green provinces like Sichuan with less than 12 percent forest cover.[39] All of China's seven major river systems are severely polluted. One of the first major public demonstrations over water pollution--a protest in the Huai River basin--pushed the Chinese government to shut down over 65,000 factories in the region between July 1996 and September 1997.[40]

China has developed several environmental plans and strategies to bring the economy and the environment into better harmony, yet it lacks the institutional capacity to implement these plans. Environmental pollution and damage to natural ecosystems are becoming serious constraints to sustainable social and economic development.

Major difficulties in protecting China’s environment include

- poor enforcement of environmental protection regulations
- a general perception that economic development must come before environmental protection
- the belief that if only more technology and more funding were available, environmental pollution could be reversed.

The Chinese government has enacted a series of laws and regulations on pollution prevention and environmental protection. Local governments, particularly governments below the provincial level, are often more interested in expanding the local economy than protecting the environment. This problem is serious with regard to township and village enterprises (TVEs), particularly those using outdated and highly polluting equipment. Because these TVEs are often the major source of income for the community and because local environmental protection agencies are much less powerful than local economic authorities, environmental regulations are rarely enforced.[41]

China has developed several blueprints to help guide the development of the economy and protect the environment. China's Agenda 21, developed in response to the 1992 Earth Summit in Rio de Janeiro, is, on paper at least, a model program for integrating economic and social development.[42] China also has included extensive environmental planning sections in its 9th Five-Year Plan and Long-Term Objectives To 2010. The government is focusing attention on water pollution in major rivers and lakes, sulfur dioxide emissions, and particulate emissions. In the short term, more efforts will be made to prevent pollution problems from getting worse, and in the long term, to improve environmental quality and rebuild damaged ecosystems. Besides promoting pollutant treatment, more emphasis will be given to adopting high-efficiency, advanced technologies and processes and reducing the creation of pollutants. Pollution control measures will be applied to reduce the total load and concentration of pollutant emissions. Significant effort will be made to strengthen enforcement of laws and regulations, increase public awareness of environmental protection, and improve environmental science and technology capabilities.

The Chinese government is also beginning to respond to global environmental problems such as climate change. However, China has not agreed to emissions targets or made other climate mitigation efforts because it places priority on improving living standards and believes that developed nations must first demonstrate their own commitment to reducing greenhouse gas emissions.

Environmental Pollution in China's Electric Power Industry

Coal-fired power plants rank among the major sources of pollution in China. The most serious local problems include acid rain, particulates, water pollution, solid waste, and land degradation from coal mining. (See Tables 2.8 and 2.9.) These problems, with the exception of acid rain, are not primarily related to the electric power industry but to local combustion of coal, industrial effluents, raw sewage disposal, and agriculture. Particulate emissions are a problem at older power plants but can be easily controlled (except for very fine particles) in new ones.

Table 2.8
Air Pollution from Electric Power Industry in 1994
(unit capacity >6 MW)

	Nation's total	Industrial sector		Electric power industry		
	(Mt)	(Mt)	(% of nation)	(Mt)	(% of industry)	(% of nation)
Particulates	14.1	8.1	57.1	4.0	49.2	28.1
SO_2	18.3	13.4	73.5	5.8	43.3	31.8

Source: 43

Despite significant environmental problems, the electric power industry has made notable progress in environmental protection. While installed capacity, as well as coal consumption, doubled from 1987 to 1994, emission of pollutants increased by a much smaller fraction. These reductions resulted from the implementation of laws and national policies on environment protection, increased investment in pollution control, and the development of advanced technologies.

Particulate emissions from thermal power production have largely been stabilized. The total installed capacity of coal-fired power plants with unit capacities over 6 megawatts was 55 gigawatts in 1987, and particulate emissions totaled 3.9 million tons. By 1994, installed capacity had doubled to 108 gigawatts while particulate emissions increased by only 4 percent to 4 million tons. The average particulate removal rate increased from 92 percent in 1987 to 95.6 percent in 1995. In recent years, all new, expanded, and renovated thermal power plants were required to be equipped with high-efficiency electrostatic precipitators. The number of precipitators in use, including domestic and imported units, increased from 103 in 1987 to 364 in 1994.

Table 2.9
Pollution From Coal-Fired Power Plants
(unit capacity >6 MW)

	1990	**1991**	**1992**	**1993**	**1994**
Installed Capacity (MW)	76,010	83,720	90,825	98,110	108,275
Coal Consumption (Mt)	239	262	282	306	331
Particulate Emissions (Mt)	3.6	3.6	3.9	3.8	4.0
SO_2 Emissions (Mt)	4.2	4.6	4.9	5.2	5.8
Waste Water (Mt)	842	1,255	N/A	N/A	1,873*
Ash Wash Water (Mt)	799	789	N/A	N/A	801*
Ash Wash Water Recovery (Mt)	182	215	N/A	N/A	431*
Ash and Slag (Mt)	67	75	80	86	91
Utilization of Ash and Slag (Mt)	20	23	26	30	37

* = 1995 data
Source: 44

China is now attempting to control sulfur emissions associated with power production. Several pilot plants equipped with flue gas desulfurization (FGD) facilities have been built. The total installed capacity of these power plants totals little more than 1 gigawatt. These plants still do not play a significant role in sulfur emissions control, but they are a starting point for future activities. The traditional approach to SO_2 pollution in China was to increase the height of power plant smokestacks. While higher chimneys reduce local ground concentration of SO_2, they exacerbate regional acid rain problems. Total emissions of SO_2 remain the same, but they are lofted higher into the atmosphere where conditions are favorable for acid rain formation.

The Chinese government has yet to develop a specific standard for NO_x emissions for power production, although the former Ministry of Electric Power Industry had requested that new thermal power plants with a unit capacity over 300 megawatts use low NO_x emission technologies. The requirement would help check growth in NO_x emissions if new plants are required to use the devices.

The government has also implemented policies to promote utilization of ash and slag from power production. Ash and slag utilization increased from 11 million tons in 1987 to 37 million tons in 1994 out of a total 91 million tons generated.

In 1987, only 60 percent of the water discharged from thermal power plants met national standards for water protection. This ratio increased to 76 percent in 1994. Almost no wastewater was recovered in 1987, but by 1994 the amount recovered rose to 770 million tons. In 1987, 17 coal-fired power plants discharged ash and slag directly into rivers and lakes, creating serious water pollution problems. This discharge had stopped completely by 1995.

Hydropower projects create different types of environmental concerns. Huge projects like the Three Gorges Dam cause serious impacts on ecosystems, including creating a 600-kilometer-long lake in which thermal stratification will likely lead to serious oxygen depletion. Power produced from the Three Gorges Dam also has the potential to avoid the combustion of 50 million tons of coal a year.

China has two nuclear power plants in operation. During design, construction, and operation, China has attempted to learn and adopt experiences and lessons from other countries to reduce risk and ensure plant safety. These two nuclear power plants have only operated for a short time--Qinshan for five years, Daya Bay for three years--and the amount of nuclear waste generated so far is small and has not created serious environmental problems. Safe operation of nuclear power plants and disposal of high-level radioactive waste is essential if China hopes to fulfill its long-term commercial nuclear plans.

Reducing Environmental Problems in China's Electric Power Industry

The most critical environmental task, in terms of power generation, is to reduce sulfur emissions, especially in so-called acid rain control regions (ARCR) and SO_2 emission control areas (SECA). Emissions of nitrogen oxides, particulates, carbon dioxide, and heavy metals as well as water pollution, excessive water consumption, land subsidence, and ash and slag disposal are other problems the power industry must eventually address.

Options for reducing environmental problems related to China's electric power industry include

- *Changing the energy supply structure*. Cleaner supplies, such as natural gas and renewables, could play a much larger role in reducing harmful emissions and waste products.

- *Improving efficiency in the electric power sector*. Small, older power generation units can be retrofitted or replaced by large-capacity--meaning larger than 200 megawatts--units. New thermal power plants could be built with a unit capacity greater than 300 megawatts. Supercritical boiler-turbine units, generating steam pressure greater than 237 atmospheres (24 megapascals), are more efficient than subcritical boilers and could be used more widely in the Chinese market. Greater attention could also be placed on reducing transmission and distribution losses, optimizing plant dispatch operations, and lowering in-plant power usage.

- *Improving fuel quality*. Using high quality coal (low ash and sulfur content with high heat value) or "washing" the coal can significantly reduce pollution. In southern and eastern coastal areas, imported coal could be an alternative. High-quality coal, however, may have priority use in industrial and residential boilers where local pollution is more serious than from power plants.

- *Locating coal-fired power plants wisely*. Mine-mouth, coal-fired power plants can be built in coal production areas of the north where the environment has a higher capacity for emissions. Rather than transporting coal to other regions, transmitting electricity can be more beneficial to the environment, though water shortages will present a challenge for cooling.

- *Using SO_2 reduction technologies*. China can benefit from mature technologies in developed countries such as flue gas desulfurization. By 2000, China plans to install desulfurization equipment on 10 gigawatts of coal-fired capacity.

- *Developing advanced energy technologies*. Advanced technologies, such as integrated gasification combined cycle and pressurized fluidized bed combustion, are still in the demonstration stage. China also lacks the capacity to produce large, world-class gas turbines for use in the power sector. These turbines can be used with a wide range of fuels from gasified coal to natural gas and light oil and already achieve efficiencies approaching 60 percent in industrialized countries. Other technologies such as fuel cells, photovoltaic cells, and wind turbines may be important alternatives to solve energy and environmental problems in the future.

Environmental Protection Laws and Regulations

Environmental protection laws can play a significant role in controlling pollution from the power industry. Chinese laws in this field include the “Environmental Protection Law,” the “Air Pollution Prevention Law,” the “Water Pollution Prevention Law,” and the “Solid Waste Pollution Prevention Law.”

These environmental laws require that project developers conduct environmental impact assessments during the feasibility analysis of all projects, including power projects, and that environmental protection facilities be designed, constructed, and operated in all stages of project development. Environmental protection agencies must assess and supervise these facilities. No project can be legally operated before meeting environmental protection requirements. Power plants, as well as other large-scale projects, built in acid rain control regions and SO_2 emission control areas, must use low-sulfur coal or, if high-sulfur coal is used, the plants must use equipment to reduce SO_2 emissions. Existing enterprises using high-sulfur coal should take measures to reduce SO_2 emissions.

Government agencies in the power sector have also made efforts to improve the quality of coal supplies to reduce pollution. The average sulfur content in coal supplied to power plants decreased from 1.2 percent in 1988 to 1.1 percent in 1994. This small change lowered annual SO_2 emissions by 450,000 tons.

Because thermal electric power production is a major source of pollution, it tops the government's list of sectors to address. According to the Chinese government’s environmental protection plan for the electric power industry, year 2000 particulate emissions must be held to 1995 levels, and SO_2 emissions in sensitive areas (ARCR and SECA) must be strictly controlled. Many hurdles must be overcome to reach these goals, however, especially relating to enforcement and financing.

China has no specific plans to reduce greenhouse gas emissions from power production. Several recent studies indicate that energy conservation and efficiency will be key measures in the near term if the country does take action.[45] Development of hydropower resources will be given more attention in the near future, while renewable energy sources will play a larger role in the long term. Limited energy resources, however, will make coal the major energy source for power production into the foreseeable future. As long coal remains dominant and demand for power continues increasing, greenhouse gas emissions from the power sector will continue to grow.

Foreign Investment and Market Barriers

Foreign Investment in the Electric Power Industry

The Chinese government plans to expand installed capacity by 15 gigawatts per year to 290 gigawatts by the year 2000. In addition, authorities plan to refit 40 gigawatts of older capacity. The central government expects to provide 40 percent of the required funding, to obtain another 40 percent from other domestic sources, and 20 percent from international markets. The Chinese must raise at least $8 billion per year for power generation--a daunting task.

In 1995, investment in power sector infrastructure totaled $10 billion, including foreign funds of $1.1 billion. Foreign funds used in China are primarily loans from multilateral financial institutions such as the World Bank, Asian Development Bank, and foreign governments like Japan. Because these sources of foreign funding will not meet financial demand in the future, China is trying to attract more foreign direct investment (FDI) from private sources. FDI accounts for about 10 percent of the total foreign funds used in China. Because the electric power industry is regarded as a fundamental infrastructure industry, the Chinese government is encouraging foreign investment in the industry. Foreign investors can wholly own enterprises or participate in joint ventures and cooperative ventures with Chinese partners. They can also become involved in China's market by purchasing stock issued on domestic and international stock markets.

One of the newest ways of investing is in build, own, transfer (BOT) projects. China tested its first BOT project at the Shajiao B coal-fired power plant in the late 1980s. The Chinese government is now apparently backing this approach. The first real commercial electric power BOT project was implemented in 1995 when Electricite de France and GEC Alsthom won a competitive bidding process for the Laibin B coal-fired project. Other BOT projects now underway include Changsha Power Plant and Jinghong hydropower project. BOT projects give operators incentives to boost profits by reducing costs because prices are negotiated on a cost-per-kilowatt-hour basis, rather than a return on investment.

Key Barriers to Foreign Investment in the Electric Power Industry

Although the Chinese government has improved market conditions for investment in the power sector, significant barriers still exist including

- *Risk*. Foreign investors perceive higher economic, political, and legal risks than the government acknowledges. Although these investors are generally optimistic about the future market in China, they often mention that the ratio of profitability to risk is higher in other countries.

- *Return on investment.* The Chinese government allows a 12 to 15 percent rate of return on investment in infrastructure projects. Foreign investors expect higher rates based on the perceived risks mentioned above. Few foreign companies will invest in any large project if return on investment is less than 15 percent, even at their own domestic facilities.

- *Complexity*. Foreign investors may not be familiar with the complex project approval process in China. Approval is required from many governmental agencies at different levels, each of which takes time and money. This process is not transparent to newcomers.

- *Legal issues*. Foreign investors are not confident that the Chinese legal system will be unbiased in the event of a dispute with local counterparts. They also worry about the enforcement of contracts with power grid operators and fuel suppliers. Negotiating power purchasing agreements has thus been difficult and time-consuming.

- *High tariffs and taxes*. Foreign investors expect low import tariffs and tax rates. Import tariffs for power units smaller than 350 megawatts are 38 percent, while larger units are assessed at only 6 percent.[46] High income taxes also reduce net profit. While the government has reduced import tariffs in recent years, some favorable policies enjoyed by foreign investors, including tax deductions and exemption policies, were also abolished.

- *Lack of mutual understanding*. Chinese and foreign partners often lack a mutual understanding of each other's culture and business practices, hindering cooperative projects. Both sides need more experience cooperating in the electric power market.

3. Electricity Demand Projection

This section presents the results of the electric power demand forecast used in the study and describes variables related to future demand. Regional power demand generated in this forecast defines the amount of power needed in the least-cost analysis.

Regional Disaggregation Used in the Study

China is the world's third largest country in land area with a wide distribution of energy resources and uneven economic development. This study evaluates demand and costs in seven regions to account for the availability of energy and other natural resources, economics of power production and transmission, environmental conditions, and availability of data and information. (See map on page xi.) Regional groupings do not include Xinjiang, Xizang (Tibet), and Hainan Island because of their relatively small economies and independent power grids. A brief discussion of the characteristics of the seven regions follows.

North China

North China is home to 140 million people and includes the municipalities of Beijing and Tianjin, the provinces of Hebei and Shanxi, and the western part of the autonomous region of Inner Mongolia. The region is rich in coal deposits but poor in hydropower resources. This is the most important coal-producing region in the country and provides more than 90 percent of the coal transported to the rest of China. The north will continue to dominate China’s coal production and will be the center for mine-mouth power generation. In some areas of Inner Mongolia Autonomous Region and Hebei provinces, wind resources are also favorable.

Northeast China

The northeast region, with a population of 100 million, covers Heilongjiang, Jilin, Liaoning, and the eastern part of Inner Mongolia. Sometimes referred to as China's "rust belt," the economy of this region is dominated by heavy industry and raw material production. The region is an important base for energy production with its oil deposits accounting for about half of the country's total. This oil, however, serves the entire nation, so coal still dominates regional energy use. Coal supplies 75 percent of the region's primary energy and 80 percent of its power generation. This region is short of primary energy for power generation because its coal output is limited and remaining hydropower resources lie on international borders, thus constraining their development. To bridge the gap between energy supply and demand, coal transfer from the north region is required.

Northwest China

Northwest China includes the provinces of Shaanxi, Gansu, and Qinghai, and the autonomous region of Ningxia, and is home to 70 million people. The upper reaches of the Yellow River flow through the region and offer large hydropower potential. The Yellow River between Longyiangxia and Qingtongxia represents one of the three largest hydropower bases in the country. Coal reserves in Shaanxi, Ningxia, and Gansu are also abundant.

Southwest China

This region is home to almost 240 million people and includes the Chongqing municipality, Sichuan province, Guizhou province, Yunnan province, and Guangxi Autonomous Region. Hydropower resources from the Yangzi, Lancang, and Hongshui Rivers are distributed in this region, representing 50 percent of the country's exploitable hydropower resources. Coal reserves in the region are also comparatively rich. Most of this coal, however, is high in sulfur content--ranging between 2 and 4 percent--and thus SO_2 emissions are high.

Central China

Central China, with over 250 million people, includes Henan, Jiangxi, Hubei, and Hunan provinces. The region is short of energy resources despite construction of the Three Gorges Dam, which will be the largest hydropower station in the world. Only Henan has outstanding coal deposits, accounting for over 80 percent of the region’s total. Over 84 percent of the region's exploitable hydropower resources, which vary significantly by season, are concentrated in Hubei and Hunan.

East China

This region encompasses Shanghai municipality and the provinces of Jiangsu, Anhui, Zhejiang, Shandong, and Fujian. Its population totals 308 million. It is the most economically developed region in China and the most populated. In 1995, economic output of this region accounted for over one-third of the country's GDP. Fast economic growth is expected to continue, accompanied by rapid energy and electricity demand increases. However, the region lacks primary energy resources. Coal reserves and hydropower potential amount to only 5 and 3 percent of the nation’s total, respectively. Until now, the region’s energy supply has been heavily dependent on coal transported from the north China coal base. Transportation bottlenecks and environmental pollution continue to plague this region. To alleviate energy shortages and improve the energy structure of the region, energy imports and the development of supplemental energy, such as wind power, have been recommended. The coastal area of this region has also been designated as a priority area for development of nuclear power plants. Natural gas-based generation technologies could also play an important role in the future.

Guangdong

Guangdong Province is officially part of southwest China, but in this study we treat it as a separate region because it is has different economic and energy characteristics. About 70 million people live in the province. Like east China, Guangdong has a vigorous economy and a deficiency of primary energy. Most energy supply is imported from other regions or from abroad. Guangdong alone accounts for over 9 percent of China's GDP.

Socioeconomic Baselines

Electric power demand is projected according to the development plans of the central and regional governments, and to the reality of local conditions. Results from these demand forecasts will be used in Section 6 as the basis for analyzing the economic and environmental costs of electric power development in China. The year 1990 was chosen as the base year, while 1995 was used to calibrate the model. Target years include 2000, 2005, 2010, 2015, and 2020. Before moving to the projection of future demand, we briefly discuss related socioeconomic issues.

Evolving Electric Power Demand

With the rapid development of China's economy and improved living standards for many Chinese people, the demand for high-quality energy, especially for electric power, will increase significantly. The driving forces behind these increases include the following:

- More electric machinery will be used as agricultural processes are increasingly modernized.
- Economic growth will remain high as industrial structure continues to evolve and state-owned enterprises operate more efficiently in a market economy.
- Industries with high electricity intensities, including petrochemicals and construction materials, will play larger roles in the future.
- High value-added industries and products relying on high-quality electric power will develop quickly.
- Tertiary services will increase significantly and consume more electricity.
- Electricity consumption in the residential sector will increase with rising standards of living.
- Electricity as a clean, convenient, high-quality energy source will replace other forms of energy and new electricity users will emerge with the rationalization of electricity prices.

On the other hand the development of advanced technologies will reduce electricity consumption per unit of economic output. Traditional heavy industry is no longer the sole driving force behind much of China's growth. Light industrial and service sector growth is outpacing that from the more energy-intensive heavy industry sector. Energy efficiency is also receiving more attention as the market economy develops; hence, the growth rate of electricity consumption will tend to be held in check.

Population

Population growth is an important variable in economic and energy forecasts. Annual growth rates have remained relatively low in China, ranging between 0.8 and 1.6 percent each year from 1991 to 1995. Some observers argue over the validity of these growth rates, particularly in rural areas. Guangdong had the highest rate of growth at 1.6 percent and the northeast the lowest at 0.8 percent. The nation as a whole grew by 1.2 percent a year, giving a doubling time of 58 years. In 1995, the population of the seven regions totaled almost 1.2 billion, accounting for 97 percent of the nation's total (See Table 3.1.). China's success in controlling population growth has resulted in tremendous additional energy conservation.

Table 3.1
Population of the Seven Regions in 1995

	(Million)	(% of National Total)	1991-95 Annual Growth Rate (%)
North	140	12	1.2
Northeast	104	9	0.8
East	308	25	0.9
Central	253	21	1.0
Southwest	234	19	1.2
Northwest	69	6	1.4
Guangdong	69	6	1.6
Seven-Region Total	1,176	97	1.1
National total	1,211	100	1.2

Source: 47

Gross Domestic Production

Gross domestic production grew very quickly in the seven regions between 1991 and 1995, ranging from 9 percent a year in the northeast to 19 percent in Guangdong. The eastern region, accounting for over one- third of the country's economy, grew on average by more than 16 percent a year from 1991 to 1995. The northeastern region grew a little more than half as quickly at 9.4 percent a year. By 1994, the total GDP of the seven regions reached 5.6 trillion Yuan, 97 percent of the total. (See Table 3.2.)

Table 3.2
Real GDP of the Seven Regions in 1995

	(billion Yuan)	(% of National Total)	1991-95 Annual Growth Rate (%)
North	709	12	12.0
Northeast	594	10	9.4
East	2,031	35	16.3
Central	880	15	12.4
Southwest	698	12	11.7
Northwest	189	3	9.5
Guangdong	538	9	19.1
Seven region total	5,638	97	13.7
National total	5,826	100	12.0

Source: 48

Economic Structure

China's industrial sector accounted for an unusually high percentage of the economy compared to agriculture and service sectors. Guangdong's industry accounted for over half of the province's economy, similar to the eastern region. Agriculture in the southwest accounted for the largest percentage of the economy in any of the seven regions while its industrial percentage was the smallest. (See Table 3.3.)

Table 3.3
Economic Structure of the Seven Regions in 1995
(%)

	Primary	Secondary	Tertiary
North	17	47	36
Northeast	18	49	33
East	17	50	32
Central	28	42	30
Southwest	29	41	30
Northwest	22	43	36
Guangdong	16	52	32
National Average	21	48	31

Note: Primary sector includes agriculture; secondary sector includes industry and construction; tertiary sector includes transportation, communication, commercial, and service sectors.
Source: 49

Current Electricity Consumption and Characteristics

Total electricity consumption in 1995 reached 989 terawatt-hours, increasing at an annual rate of almost 10 percent from 1991 to 1995. Electricity consumption per capita was 828 kilowatt-hours in 1995, only one-third of the world average. Per capita consumption increased at an annual rate of 8.7 percent over the period 1991 to 1995. (See Table 3.4.)

The northeast region has the highest electricity consumption per capita, almost 50 percent above the national average. Guangdong province follows, indicating its relatively high level of industrial and residential electricity use. The southwest region has the lowest per capita consumption, about 60 percent of the national average.

Table 3.4
Regional Electricity Consumption Statistics

	1995 Consumption (TWh)	1995 Consumption Per Capita (kWh)	1991-95 Consumption Growth (%)	1991-95 Consumption Growth Per Capita (%)
North	158	1,128	9.1	7.8
Northeast	127	1,225	6.0	5.2
East	283	919	11.3	10.3
Central	150	592	9.3	8.1
Southwest	115	491	11.3	10.0
Northwest	64	920	7.6	6.1
Guangdong	79	1,147	18.2	16.4
National Total	1,002	828	10.0	8.7

Source: 50

Like China's elasticity of energy demand, the elasticity of electricity demand (defined as the rate of growth in electric power consumption divided by the rate of growth in the economy) is very low. Guangdong and the southwest region had elasticities close to 1 while the east and northeast regions had values below 0.7. Most developing countries have elasticities above 1.0.

Table 3.5
Annual Electricity Consumption Growth and Elasticity by Region (1991-1995)

	GDP growth (%)	Electricity growth (%)	Elasticity of Demand
North	12.0	9.1	0.76
Northeast	9.4	6.0	0.65
East	16.3	11.3	0.69
Central	12.4	9.3	0.74
Southwest	11.7	11.3	0.96
Northwest	9.5	7.6	0.80
Guangdong	19.1	18.2	0.95
National Total	12.0	10.0	0.83

Source: 51

Regional Projections

The Ninth Five-Year Plan projects 8 percent GDP economic growth to 2000 and 7.2 percent from 2001 to 2010. Beyond 2010, most experts expect economic growth of around 6 percent, at least until 2020.

This study draws heavily on results of analyses done by the Energy Research Institute, which has used the MEDEE/ENV model to project future electric power demand.[52] The key drivers of this model are assumptions for economic growth and elasticity of demand for power. (Sees Table 3.6 and 3.7 for these assumptions.)

Table 3.6
Electricity Demand Growth Rate and Electricity Elasticity

	1991-95	1996-2000	2001-05	2006-10	2011-15	2016-20
Growth Rate (%)	10.0	6.8	6.5	5.6	5.1	4.5
Electricity Elasticity	0.83	0.84	0.84	0.84	0.80	0.80

Table 3.7
Annual Electricity Growth Rate by Region
(%)

	1991-1995	1996-2000	2001-05	2006-10	2011-15	2016-20	1996-2020
North	9.1	6.8	6.3	5.8	5.3	4.6	5.8
Northeast	6.0	5.8	6.0	5.2	4.6	3.9	5.1
East	11.3	7.1	6.5	5.6	5.0	4.4	5.7
Central	9.3	7.1	6.6	5.8	5.4	4.8	5.9
Southwest	11.3	6.9	6.6	5.8	5.5	4.8	5.9
Northwest	7.6	6.9	5.9	5.1	5.5	4.8	5.6
Guangdong	18.2	7.4	6.5	5.6	4.8	4.1	5.7
Total	10.0	6.8	6.5	5.6	5.1	4.5	5.7

The model calculates regional electricity demand through 2020 at five-year intervals. (See Tables 3.8 and 3.9.) Electricity demand will quadruple over the next 25 years as a result of rapid improvement of living standards. These results are comparable to those of other studies. (See Figure 3.1.) However, electricity consumption per capita will still be 2,670 kilowatt-hours in 2020, much less than in developed countries at present. The shares of electricity consumption in the seven regions will remain stable with the southwest, northwest, and central regions increasing slightly and the northeast and northwest regions decreasing a little.

Table 3.8
Total Electricity Demand Forecast

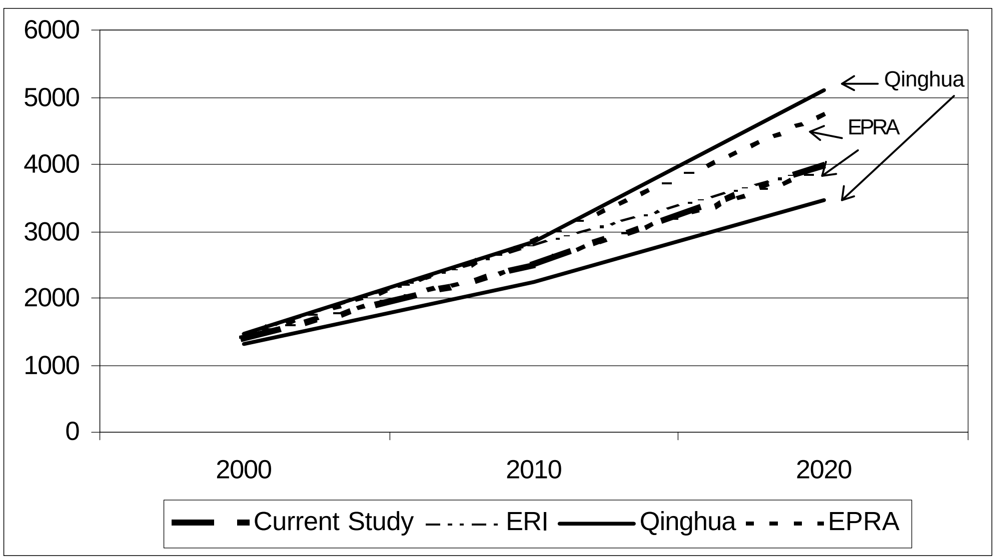
Year	1995	2000	2005	2010	2015	2020
Electricity demand (TWh)	1,002	1,390	1,900	2,500	3,210	4,000
Demand per capita (kWh)	828	1,069	1,406	1,786	2,219	2,667

Table 3.9
Electricity Demand Forecast by Region (TWh)

	1990	1995	2000	2005	2010	2015	2020
Northern	102.3	157.9	219.6	298.2	395.0	510.4	640.0
Northeast	94.8	127.2	168.2	225.2	290.0	362.7	440.0
Eastern	165.6	282.6	397.5	543.4	715.0	911.6	1128.0
Central	96.3	150.0	211.3	290.7	385.0	500.8	632.0
Southwest	67.2	114.6	159.9	220.4	292.5	382.0	484.0
Northwest	44.4	63.9	89.2	118.9	152.5	199.0	252.0
Guangdong	34.1	78.8	112.6	153.9	202.5	255.5	312.8
Regional Total	604.8	974.9	1,358.3	1,850.7	2,432.5	3,122.0	3,888.8
National Total	623.0	1,002.3	1,390.0	1,900.0	2,500.0	3,210.0	4,000.0

Source: 53

Figure 3.1
Electric Power Demand Forecasts of Other Institutions (TWh)



	(TWh)	(TWh)	(TWh)
Current Study (1998)	1390	2500	4000
ERI (1995)	1470	2800	3960
Qinghua University (1994)	1325-1470	2230-2830	3450-5100
Electric Power Research Academy (1994)	1411	2501-2845	3900-4745

Source: 54

4. Power Sector Technology Assessments

This section outlines the availability of energy resources and assesses the characteristics of power generation and environmental control technologies. It describes the current state of power system development in China and projects the evolution of technologies and costs over the near term.

Each section provides a brief technical overview along with a discussion of relevant environmental and economic issues, beginning with a discussion of the sources of energy that could be used to generate electric power.

Sources of Energy for Power Generation

Coal

Coal is the most abundant energy resource in China. It is mined primarily in the northern provinces of Shanxi, Heilongjiang, and Shandong.[55] This coal is generally of high quality, with an average heat content of 21 GJ per ton and sulfur content below 1 percent. Coal from Sichuan, Guizhou, and Hunan provinces, however, has high sulfur content, ranging from 2 to 5 percent, and contains more than 25 percent ash. The geographic mismatch between coal production and consumption centers requires the transport of hundreds of millions of tons of coal each year. Less than 20 percent of this coal is washed to remove inert material before transport, overloading an already weak transport infrastructure. The environmental effects of consuming almost 1.4 billion tons of coal each year, often with little or no air pollution control, are devastating in some areas.

Table 4.1
1995 Coal Reserves in China by Region (billion tons)

	Total Reserves	Accumulated Proven Reserves	Remaining Proven Reserves
North	2,018	509	501
Northeast	68	35	31
East	225	58	54
Central	129	31	28
Guangdong	3	1	0.6
Southwest	297	86	85
Northwest	2,323	304	302
Total	5,059	1,034	1,001

Source: 56

Total coal resources are estimated at five trillion tons, with proven reserves of one trillion tons. (See Table 4.1.) Proven reserves could supply China's current demand for over 750 years. Central government-owned coal production enterprises in 1996 produced 40 percent of all coal, collective and privately-owned enterprises mined over 45 percent, while local government mines provided 15 percent. The practice of transporting coal from the north to the south and from the west to the east is expected to continue, and importing coal from abroad may become an option in coastal areas in the southern region.

Hydropower

China has the most abundant hydropower resources in the world, with an estimated potential for 380 gigawatts.[57] Installed hydropower capacity is just over 50 gigawatts, only a small fraction of the potential. Hydropower could supply much of China’s needs, but rivers with high potential are located far from load-centers and are heavily laden with silt. Nevertheless, China has an ambitious program to build many large hydropower stations over the next 20 years. The Three Gorges Project is only one of several projects on the drawing board with a capacity of 5 gigawatts or more. Most of these plants will lie on the mid- and upper-reaches of the Yangzi, Yellow and Lancang Rivers.

More than half of China's hydropower resources are concentrated in the southwest region. (See Table 4.2.) Hydropower potential is also abundant in the central and northwest regions. A larger portion of those hydropower resources is exploited in Guangdong and the east and northeast compared to other regions because they are close to load centers. Hydropower resources in the southwest and northwest regions are alternatives for the east region where energy resources are in short supply.

Table 4.2
Hydropower Resource in China by Region (GW)

	Exploitable Capacity	1995 Installed capacity	Exploitation Rate (%)
North	7	1	18
Northeast	12	5	37
East	13	7	57
Central	52	13	24
Guangdong	6	5	82
Southwest	190	15	8
Northwest	33	5	16
Total	313	50	

Note: Exploitable capacity and installed capacity are regional, not national, totals.
Source: 58

Natural Gas, Liquified Natural Gas, and Coal Bed Methane

Natural gas serves as one of the world’s most important energy sources, yet China uses gas for less than 2 percent of its total energy needs. Less than 1 percent of China's electric capacity is based on natural gas. Given China's large reserves of coal and oil, however, geologists in China should find more gas because the formation processes of the three fossil fuels are so similar.

According to a recent resource assessment, China's theoretical total natural gas reserves amount to 38 trillion cubic meters, about 9 percent of the world's total in 1996.[59] Roughly one-fifth of these reserves are on-shore. Proven reserves, however, total only 13 trillion cubic meters and exploitable reserves are about 7 trillion cubic meters, while proved reserves range from 1.2 to 5.3 trillion cubic meters.[60]

China's natural gas is located mainly in the southwest, central, northwest, and off-shore regions. Sichuan, where gas production is not associated with oil production, has been the historic source for much of China's natural gas production. Natural gas output from the northwest, on the other hand, results from gas associated with oil production and accounts for most of the remaining on-shore production. Gas production will grow most rapidly in the northwest region and off-shore. (See Table 4.3.)

China also has reserves of coal bed methane (CBM) amounting to 35 trillion cubic meters. The country has recently gone from viewing CBM as a safety hazard to acknowledging it as a potential new source of clean energy. Tapping methane in China's notoriously gassy coal mines would raise coal-mine productivity and improve safety.[61] China recently signed a first-of-its-kind contract with a major international petroleum company to jointly extract CBM reserves in Anhui province. The field is thought to contain 60 billion cubic meters (BCM) of methane reserves, capable of producing 500 million cubic meters of gas a year.[62]

Table 4.3
Estimated Future Natural Gas Production by Region (billion cubic meters)

	2000	2010	2020
Northeast	5	5	4
North	1	2	2
East	2	5	6
Central	13	1	1
Southwest	12	16	19
Northwest	8	27	41
Guangdong (off shore)	7	2	20
Total	35	71	93

Source: 63

Because Chinese gas reserves are far from consumption centers, and because China has yet to develop large-scale fields, the international market may become an important source of natural gas supply for some regions. China recently signed a memorandum of understanding with Russia to develop a pipeline to transport 30 billion cubic meters of gas per year from Siberia to China's eastern coast. Discussions of other pipeline projects are underway. Liquified natural gas (LNG) may also be a major new energy source for southern and eastern coastal regions.

Gas imports could exceed 25 BCM (1 EJ) by 2010. (See Table 4.4.) LNG imports could add 10 BCM in 2010 and 20 BCM by 2020. A high priority for natural gas use will initially, however, be the direct use of gas to substitute for coal in heating, cooling, and industry. Coal use for these applications causes the most serious air pollution. An accelerated development program could result in more fuel switching than would occur in the baseline case and spill over to provide energy for some power generation.

Table 4.4
Estimated Natural Gas Imports by Region, billion cubic meters

	2005	2010	2020
Northeast	10	10	10
North	--	5-15	15
East	--	5-15	15
Total	10	20-40	40

Source: 64

Petroleum

Petroleum resources in China are estimated at 89 billion tons, while exploitable reserves are estimated at around 15 billion tons. In 1996, petroleum production reached 159 million tons.[65] China relied on oil 30 years ago to fire some of its thermal power plants, but as domestic production stagnated and demand from the industrial and transportation sectors skyrocketed, the country converted almost all thermal power plants to coal. Petroleum imports are expected to continue growing during the coming decades, but very little oil will be used for electric power generation.[66]

Nuclear

China has an ambitious plan to develop nuclear power. The country currently has three reactors in operation with 2,100 megawatts of capacity. In 1996, nuclear reactors generated about 14 terawatt-hours of power, accounting for about 1 percent of all generation. Three projects are currently under construction and up to 40 gigawatts of capacity additions are planned by 2020. The Energy Research Insitute was not able provide an estimate of China's uranium reserves for this study.

Biomass

Biomass energy provides 220 million tons of coal equivalent each year and is used mainly in rural areas.[67] Firewood and straw are the main fuels and are used for heating and cooking in households and kiln heating in rural industries. Human and animal wastes are also used to produce biogas. According to estimates from energy analysts, total biomass demand could reach 210 million tons in 2000, 180 million tons in 2010, and 150 million tons in 2020.[68] These figures suggest that economic growth and urbanization will shift demand from biomass to high-quality energy sources. Accordingly, less biomass energy will be available for direct use, and only a small proportion could be used for power generation. Biogas-fired power generation is being examined in southern regions of the country. In the future, most biomass energy will be used to provide heat or to produce biogas as household fuel. Biomass-fired power was not included in the modeling of this study because Chinese researchers believe the technological, organizational, and economic requirements would be too stringent for China's rural economy to handle. Changing this persepctive will require substantial changes in cost and technological sophistication.

Other Renewables

Exploitable wind power resources in China amount to 250 gigawatts. Most of China's world-class wind resources are located in Xinjiang, Gansu, and Inner Mongolia, far from population centers. Excellent sources also exist along the southern and eastern coastal regions.

Total high-temperature geothermal resources, defined as waters above 150 ºC, are estimated at under 7 gigawatts. Ninety percent of these resources are concentrated in Tibet and most of the remainder in Yunnan.

China also has large solar energy resources. Solar radiation in western China is strong throughout most of the year and falls in regions of sparce population. China's solar resources are concentrated in Tibet and Xinjiang, although the northeast also receives significant sunshine.

Environmental Pollution Control Technologies

Coal Cleaning

The easiest and cheapest pollution control for coal combustion is coal washing to remove ash and sulfur. Less than 20 percent of the coal burned in China is washed, even though washing removes 10 to 40 percent of sulfur and up to 60 percent of ash.

Cleaning coal would provide relief for China's overburdened rail system because less useless mass would be transported. Simple coal cleaning costs from $1 to 5 per ton, more if advanced treatment methods are used. (See Table 4.5.) Many developing countries have no incentive to clean coal because electricity prices do not vary with coal quality or with impact on power plant performance.[69] Water scarcity in the north, however, will prohibit some of China's coal from being washed even though the barrier mentioned above has been partially removed.

Electrostatic Precipitators

Electrostatic precipitators remove over 99 percent of particulate emissions and are required on all new power plants in China. Typical costs for new precipitators designed to remove up to 99.7 percent of particulates range from $30 to 60 per kilowatt in China. Higher collection efficiencies can double these costs. Effective precipitators, however, add only 2 percent or so to the cost of power.

Table 4.5
Performance and Cost of Power Plant Emission Control Technologies

Technology	SO_2 Removed (%)	NO_x Removed (%)	Capital Cost ($ per kilowatt)	Extra O&M (cents per kilowatt-hour)
Coal Washing	Up to 40	Up to 60	1-5/ton of coal	--
ESP	0	Up to 99	30-90	0.03
Baghouse	0	Up to 99.9	40-60	0.03
Combined SO_x/NO_x	Up to 90	--	150-300	0.5-0.8
Dry FGD	70 – 90	--	80-150	0.2-0.3
Wet FGD	Up to 95	--	100-200	0.1-0.3

Source: 70

Baghouse Filter

Fabric, or baghouse, filters are now in greater use in industrialized countries because they are even more efficient at removing particulates from the power plant emission stream than electrostatic precipitators. When regulations require collection efficiencies above 99.5 percent and low-sulfur coal is being used, baghouse filters may be the most cost-effective technology. The slightly higher capital costs may be warranted for power plants that will be constructed near urban centers because precipitators miss very small particulates, which can cause serious damage to human respiratory systems.

Acid Rain Control

At least six types of post-combustion technologies are in use to reduce acid rain-causing emissions from power plants. None of these technologies offer a simple, cheap solution to removing sulfur and nitrogen oxides from the emission stream. They are generally complex and require a significant amount of auxiliary power. However, they remain the most effective way of preventing even more damaging pollution if high-sulfur coal must be used.

The six technologies include wet and dry flue gas desulfurization, or scrubbers, sorbent injection, selective and nonselective catalytic reduction, flue-gas irradiation, adsorption/regeneration, and other electrochemical processes. In this analysis, we restrict our discussion to scrubbers (both wet and dry) and combined SO_x/NO_x control technologies because they play the largest role in industrialized countries and will probably offer the most cost-effective treatment in China in the near term.

Wet scrubbers can remove 80 to 90 percent of the sulfur dioxide from power plant flue gas. More can be removed with expensive additives. In the basic system, calcium-rich slurry is sprayed onto the flue gas inside a large vessel after particulates have been removed from the post-combustion gas stream. The calcium reacts with the sulfur dioxide to form calcium sulfite, which is collected and dried. It can later be disposed of in landfills or sold as gypsum. Unfortunately, wet scrubbers usually lower plant efficiency by about 1 to 2 percent and add capital costs of $100 to $200 per kilowatt.

Dry scrubbers also use calcium-rich slurry to create a dry calcium sulfite mixture in the bottom of the mixing vessel. Dry scrubbers generally remove less sulfur dioxide than wet scrubbers--only about half--and remain to be proven in use with high-sulfur coal. Dry scrubbing is cheaper and simpler than its wet counterpart, costing $100 to $150 per kilowatt.

Combined SO_X/NO_X control technologies are still in the development stage, but some will soon be ready for commercialization and could play an important role in China's electricity sector. This combined technology could remove up to 90 percent of both SO_X and NO_X. The future range of costs will probably fall between $150 per kilowatt and $300 per kilowatt.[71] A combined SO_x/NO_x system is considered in the modeling presented in Sections 6 and 7.

Coal-Based Power Generation Technologies

Pulverized Coal

Pulverized coal firing has been the dominant technology for electricity generation in China since the founding of the country. It is currently used for almost 80 percent of all electric power generation. China is capable of domestically manufacturing subcritical turbine units--those using pressurized steam below 220 atmospheres--up to 300 megawatts, and may soon be able to manufacture units up to 600 megawatts. Thermal performance of steam turbines has slowly increased, mainly by adopting progressively higher steam conditions. China hopes to raise the efficiency of large domestically-produced coal-fired power generation units to nearly 40 percent early in the next century with intensified technology transfer and research and development programs.

To increase the market penetration of steam units larger than 300 megawatts, China has set import tariffs on these units at 6 percent, much lower than the 38 percent tariff applied to imported units the country is capable of manufacturing itself.[72] Because China's manufacturing capacity for coal-fired power plants is limited to 12 to 14 gigawatts per year, some imported units are required.

Chinese policy recommends that new coal-fired units be 300 megawatts or larger as a way to improve efficiency. Smaller, low-pressure units must gradually be retired. Currently, 300 megawatt and 600 megawatt subcritical units are becoming the backbone of the generation system. China can manufacture the essential elements of the former units for less than $600 per kilowatt, cheaper than any other country. China is developing the capacity to domestically build 600 megawatt and 1,000 megawatt supercritical units and plans to begin demonstrations of the smaller units soon after the beginning of the new century. These supercritical units are currently more expensive than subcritical units because they rely on imported components for at least 20 percent of the unit's value.

Several large supercritical units have already been installed. In theory, these supercritical units have efficiencies of 39 percent, although real-life operations can easily shave off several percentage points, especially after the units begin to age.[73]

In our modeling exercises, we assume two types of new coal-fired capacity additions: subcritical 300-600 megawatt units and supercritical 500-900 megawatt units.

Atmospheric Fluidized Bed Combustion

A well-developed coal-based system for power generation is the atmospheric fluidized bed combustion technology. Atmospheric fluidized bed combustion (AFBC) technology has environmental advantages over traditional pulverized coal power plants. It can reduce sulfur emissions by 70 to 95 percent and nitrogen oxides by 50 to 80 percent. The technology is based on combustion of coal in a pressurized stream of gases. Prior to combustion, the coal is crushed and mixed with a calcium-based sorbent such as limestone. Sulfur released during combustion reacts with the limestone and precipitates, thus reducing SO_2 emissions. A higher combustion efficiency can be achieved at a lower temperature than in a pulverized coal boiler, which significantly inhibits NO_x formation. Injecting ammonia into the boiler can further reduce nitrogen dioxide emissions. Steam created in an AFBC boiler is used to generate electricity much in the same way as pulverized coal systems.

There are two types of AFBCs: bubbling fluidized bed combustors and circulating fluidized bed combustors. The latter are becoming more popular in developed nations because of their improved combustion efficiency. We did not analyze the AFBC technology in the least-cost optimization because the pressurized version is considered more promising.

Pressurized Fluidized Bed Combustion

Pressurized fluidized bed combustion (PFBC) systems are basically turbo-charged versions of AFBC. They operate at efficiencies of up to 45 percent and reduce sulfur emissions even more than AFBC units. PFBC systems can operate in combined cycle configurations, using both gas and steam turbines. The gas turbine cycle generates about 20 percent of the electrical output and also supplies pressurized air at up to 20 atmospheres to the fluidized bed system. The pressurized air provides for greater combustion efficiency. A limestone sorbent is also used to capture sulfur released by the combustion of coal. Jets of air suspend the mixture of sorbent and burning coal during combustion, converting the mixture into a suspension of red-hot particles that flow like a fluid. Elevated pressures and temperatures produce a high-pressure gas stream that drives the gas turbine, and steam generated from the heat in the fluidized bed is sent to a steam turbine, creating a highly efficient combined cycle system.

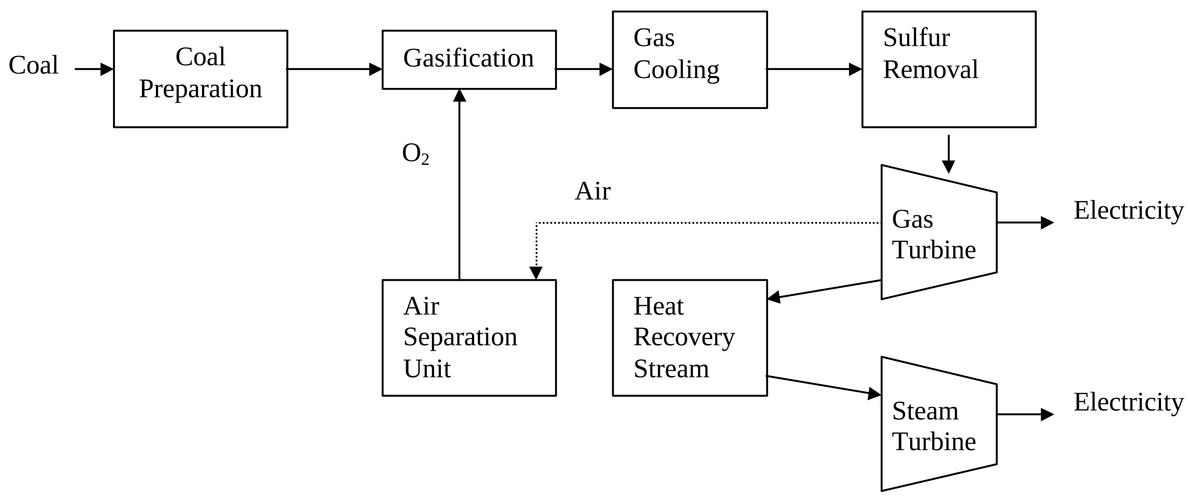
Research on PFBC systems in China began in 1980. A 15 megawatt demonstration unit was built in Jiangsu in 1991. The Ministry of Electric Power plans to build another 100 megawatt demonstration plant in the near future, followed by a 300 megawatt unit.

PFBC systems imported into China now would have high capital and O&M costs, with estimated capital costs at $1,325 per kilowatt. The initial plants would likely cost much more.

Integrated Gasification Combined Cycle

Coal gasification is a process that converts solid coal into a synthetic gas composed mainly of carbon monoxide and hydrogen. Coal can be gasified in various ways by properly controlling the temperature, pressure, and mix of coal, oxygen, and steam within the gasifier. Most gasification processes being demonstrated use oxygen as the oxidizing medium. IGCC, like PFBC, combines both steam and gas turbines (combined cycle). Depending on the level of integration of the various processes, IGCC currently achieves about 43 percent efficiency.

Figure 4.1
Schematic Diagram of an IGCC System



The fuel gas leaving the gasifier must be cleaned thoroughly of sulfur compounds and particulates. (See Figure 4.1.) Cleanup occurs after the gas has been cooled, which reduces overall plant efficiency and increases capital costs, or under high pressure and temperature (hot-gas cleanup) which has higher efficiency. However, hot-gas cleanup technologies are in the early demonstration stage.

Besides eliminating sulfur and particulate emissions, IGCC technology may also lower CO_2 emissions in China. During the gasification phase, methane-rich gas can be converted to a stream of hydrogen and carbon dioxide. The former can be directly combusted or used in fuel cells to produce power and heat with no emissions. The carbon dioxide stream could be sequestered at little extra cost according to some researchers. This method of carbon disposal is receiving renewed interest as a way to control greenhouse gas emissions.[74]

Energy planners in China once believed that IGCC would help solve the country's power problems because this technology can use domestic coal without some of the negative environmental side effects. The costs of these complex chemical plants have not yet dropped to the level to make their use widespread. Capital cost estimates are currently about $1,325, although the first plants will be more expensive. Costs will probably drop enough by 2010 to compete against pulverized coal with sulfur control devices.

Natural Gas and Petroleum-Fired Power Generation Technologies

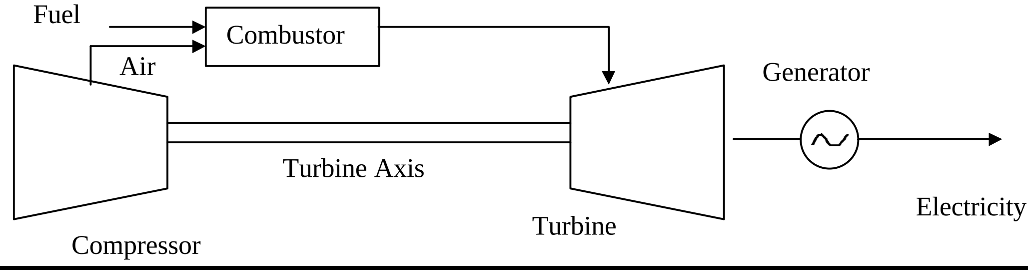
Natural gas has many advantages over coal as a fuel to generate electric power. Natural gas or oil-fed turbines enjoy lower capital costs, air pollution emissions, and construction lead times as well as greater efficiencies, modularity, and reliability compared to coal-based technologies. Until now, the main barrier to greater use of these superior technologies has been not cost but actual and the perceived lack of natural gas supply. Chinese energy specialists have also formed some of their opinions of gas turbines on outdated systems that use heavy fuel oil. Newer units are more efficient, more rugged, and cheaper.

Although more combustion turbines are currently fired using oil and petroleum distillates in China, we use the "natural gas" label to refer to both fuel sources. Because more gas will become available for power generation and petroleum demand in other sectors will continue increasing, it is likely that natural gas will soon become the dominant fuel in power turbines.

Natural Gas Combustion Turbine

Natural gas turbines generate electric power by expanding a hot gas through a series of turbine blades connected to an axis that turns a generator. (See Figure 4.2.) Combustion turbines operating in single cycle have efficiencies up to 42 percent. China has very few gas turbines in operation to produce power and thus does not have a strong manufacturing base to produce these turbines. It does, however, have excellent capability in the basic sciences of turbine theory and design and manufacture of aeroderivative turbines. Developing a greater manufacturing capability for gas turbines through joint ventures with international partners would not be difficult.

Figure 4.2
Schematic Diagram of a Combustion Turbine Power System



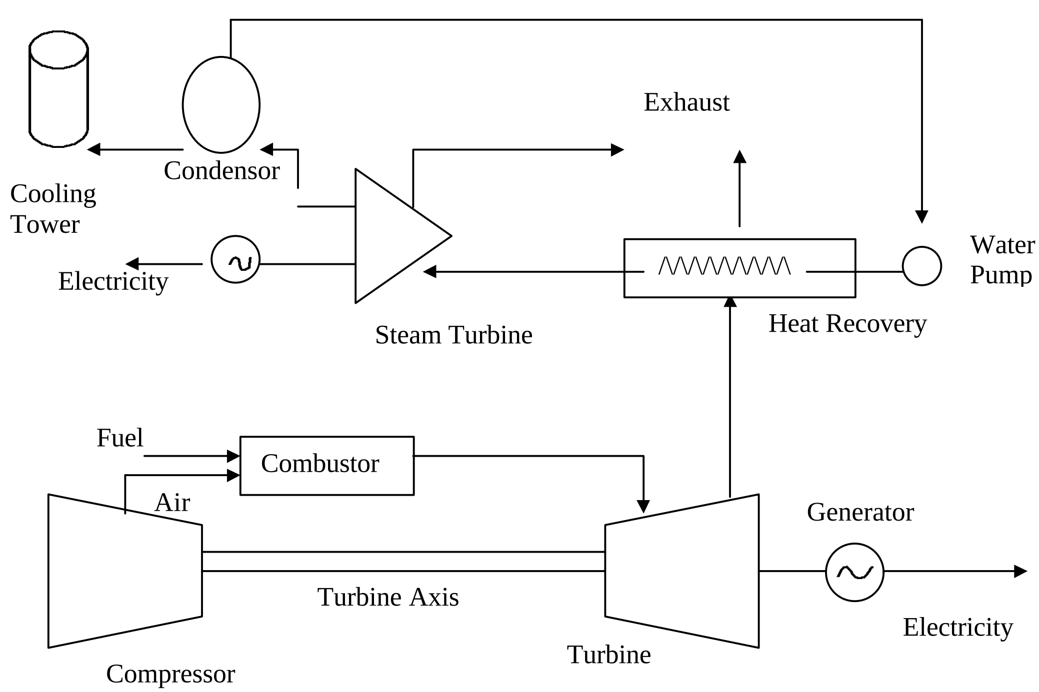
Simple cycle combustion turbines have very low capital costs and may have an important role in generating peak load power in the future. For the time being, however, combined cycle systems will have much greater potential to improve the overall economics of the Chinese energy sector.

Combined Cycle Gas Turbines

The combined cycle natural gas turbine is currently the world's most economical source for producing clean, dependable power. Current generation CCGTs have efficiencies approaching 60 percent.[75] High-efficiency and lower capital costs often offset the price advantage coal has over gas. This is also true in regions of China where coal is relatively expensive and low-cost natural gas is available.

The most critical components of gas turbines determining overall efficiency and design life are the first-stage turbine blades and combustion chamber walls. (See Figure 4.3.) Efficiency is boosted as combustion temperature increases, but the critical components mentioned above are easily damaged at the current firing temperatures of over 1200 ºC. Current mid- and large-size CCGT systems have installed capital costs ranging from $450-900 per kilowatt. O&M costs in industrialized countries are generally lower than coal-fired units and capacity factors are higher. One of the benefits of CCGT systems is that economies of scale are not dependent on large systems; even small units have relatively low capital costs.

Figure 4.3
Schematic Diagram of a Combined Cycle Gas Turbine



In this study, we use conservative performance estimates for combined cycle systems. As shown in Table 5.11, we use efficiencies ranging between 40 and 55 percent in the model. These technologies are already commercially available. PNNL researchers believe that even higher efficiency systems will soon be available for China with similar capital costs.

Fuel Cells

Fuel cells are fundamentally different from other power systems because they produce electricity as well as useable heat, through chemical reactions without combustion. The technology is a clean, quiet, and efficient method of producing power and heat from a variety of fuels. We classify fuel cells as natural gas-based technologies here because that is the most common fuel used today. Coal gas, methane, biogas and alcohols, however, can also be used.

In developed countries, rapid advances in fuel cell technology may soon revolutionize electric power generation, personal transportation, and heat and power production for buildings. Competitively priced electricity from fuel cell plants operating at nearly twice the efficiency of present-day coal technologies may begin entering markets in North America, Japan and Europe by the end of the century. Fuel cell vehicles, offering performance, cost and safety equivalent to today's internal combustion engine vehicles, but with dramatically reduced pollution and noise, could be widely available in a decade. For China, fuel cell applications in the transportation sector could have a greater economic and environmental impact than power sector applications. Because the basic technologies are the same, we discuss both power and transportation applications in this section.

Fuel cells promise higher fuel efficiency than today's technologies relying on combustion. For China, they could thus help reduce petroleum imports and enhance energy security. Fuel cells also offer local environmental benefits, including significant reductions of emissions of sulfur oxides, particulates, hydrocarbons, and noise. Fundamental research in catalysts, membranes, and other technologies required to commercialize fuel cells and hydrogen may bring spin-off applications that would benefit other industries.

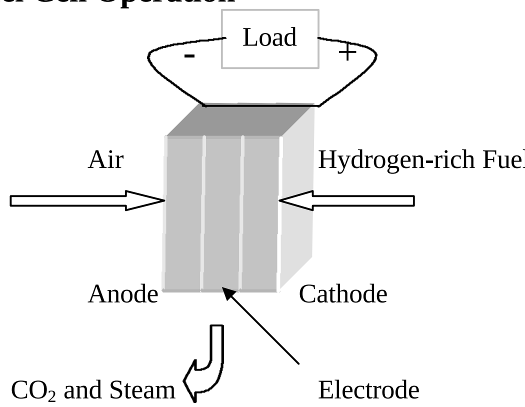
Recent scientific advances and technical demonstration efforts have enhanced the prospect that fuel cells could help society meet its energy needs sustainably. Fuel cells produce no direct carbon emissions although they may produce carbon emissions, depending on how hydrogen fuel is produced and how carbon dioxide from treated fossil fuel is handled. Key issues for their market acceptance are cost and infrastructure. Overall cost is much less a matter of the cost of producing hydrogen, which should be acceptable, but rather the capital cost of the fuel cells themselves and the transport and storage of the hydrogen fuel.

At the heart of all fuel cells is an electrolyte sandwiched between two electrodes, which separates fuel and oxidants. (See Figure 4.4.) There are several different types of electrolytes with very different properties, and very different fuel cell types have been built around them. Below, we provide a brief status report on the major types.

Figure 4.4
Schematic Diagram of Fuel Cell Operation

Overall reaction:

$2H_2 + O_2 \longrightarrow 2H_2O + e^- + \text{energy}$



Phosphoric Acid Fuel Cells
First commercialized in 1992, the phosphoric acid fuel cell is the most established fuel cell technology. It uses waste heat from the fuel cell stack to raise steam for reforming natural gas or methane into a hydrogen-rich gas for use as a fuel. It operates at temperatures around 200°C, so the waste heat is not of sufficient quality to be used in many cogeneration applications, although it can be used to heat water or provide space heating. With modifications, some steam may be available for absorption chillers. Emissions are extremely low.

PAFC technology is probably not very promising for China. First, this technology is already commercialized; additional technological breakthroughs to lower costs dramatically are unlikely. Efficiency of the current generation of cells is about 40 percent, higher than Rankine cycle systems but lower than current combined-cycle gas turbine systems. Capital costs will come down from the current $2,500-3,000 per kilowatt, but other fuel cell technologies will soon be cheaper. Finally, the PAFC technology is not suitable for transportation applications as the power density (kW/kg) is considered too low and its rather high operating temperature requires an unacceptably long start-up time.

Proton Exchange Membrane
Proton exchange membrane fuel cell technology has made extremely rapid progress over the past five years. Power densities have increased fivefold and expensive platinum loadings in the electrolyte have declined by an order of magnitude. Proton exchange membrane fuel cells, also know as solid polymer fuel cells, normally operate at 70-90° C, much lower than other fuel cell types, because of the limitations imposed by the thermal properties of the membrane itself, namely its dependence of ionic conductivity on water content.

Current designs focus primarily on transport applications because the PEM has a relatively high power density, the solid electrolyte offers safety advantages, and its low-temperature operation is inadequate for cogeneration. One possibility, however, is using stacks of PEM cells in small-scale distributed applications for power, water heating, and space conditioning. The evolution of both transport and power applications would generate economies of scale and synergy between the two markets and could make the introduction of the technology easier than for other fuel cell types.

Current research focuses on the problems of carbon monoxide catalyst poisoning, low power densities, complex stack subsystems, expensive fluorinated membranes and unstable transient operation.

Molten Carbonate Fuel Cells

Molten carbonate fuel cells are so named because the electrolyte they use is a molten alkali carbonate mixture. They operate at a temperature of about 650° C, meaning that useful heat is produced for cogeneration applications. Internal fuel reforming is possible. Efficiencies with combined cycle cogeneration systems will approach 65 percent. The first full scale-stacks have been tested and demonstration units began operation in California in 1996.

Long-term research priorities to overcome existing barriers include improving conductivity and stability of cathode materials, developing lower-cost materials and processes, optimizing components to increase power densities, and solving electrode-electrolyte corrosion problems, and increasing cell-lifetime beyond five years.

Solid Oxide Fuel Cells

The solid oxide fuel cell represents a promising technology with development only slightly behind molten carbonate fuel cells. Solid oxide fuel cell systems currently operate in a high-efficiency, high-temperature mode. A low-temperature (650-850° C), low-cost mode is being studied. In both cases, the heat produced can be used in cogeneration applications, boosting overall efficiency to near 70 percent.

There are three fundamental designs of SOFC--the tubular, planar and monolithic designs. Only the first two are currently being developed. The tubular system is relatively well developed and has completed 25 kilowatt field tests. Larger megawatt-sized demonstrations are planned for the year 2000. Planar and monolithic type SOFCs have the potential to provide even higher efficiencies and lower costs.

Research priorities include fabrication and manufacturing costs, high temperature seals and manifolding, and cascading. A major need is development of a solid electrolyte, low-temperature SOFC (650-800° C). A key research area for China lies in lowering the cost of gasifying coal to make a useful fuel supply for these fuel cells.

Nuclear Power Generating Technologies

China has on paper an ambitious plan for accelerating use of nuclear technology. Most developed countries, with the notable exception of Japan, have stopped building nuclear power plants due to their high costs. Nuclear power plants could avoid many of the environmental problems associated with coal combustion, but high-level waste disposal and the risk of accidents present environmental challenges of a different magnitude.

There are currently three nuclear power units operating in China with a total capacity of 2.1 gigawatts. (See Table 4.6.) Four other plants with a combined capacity of 6.7 gigawatts are expected to be on-line by 2005.

Table 4.6
China's Nuclear Power Plants

Plant Name	Province	Capacity	Technology	Cost ($billion)	Operational
Qinshan I	Zhejiang	300 MW	Chinese PWR	NA	1993
Daya Bay	Guangdong	2x900 MW	French PWR	3.9	1994
Qinshan II	Zhejiang	2x600 MW	Chinese PWR	NA	2003
Qinshan III*	Zhejiang	2x740 MW	Canadian HWR	3.4	2003
Ling'ao	Guangdong	2x985 MW	French	4.0	2003
Lianyungang	Jiangsu	2x1,000 MW	Russian VVER	3.0-3.5	2004-05

Note: PWR = pressurized water reactor, HWR = heavy water reactor, VVER = *Vodo-Vodyannoy Energeticheskiy Reactor* (water-cooled, water-moderated, in Russian; equivalent to western PWR designs).
* - planned.

In addition to these plants under construction, the government hopes to boost nuclear capacity to 20 gigawatts by 2010, 30 gigawatts by 2020, and 50 gigawatts by 2050. Given the difficulties encountered in financing these plants, however, many independent experts find these targets overly optimistic.[76] Nuclear power plants are only being considered on the diverse eastern coast where coal is difficult to obtain or expensive.

China currently has the capability to manufacture about 70 percent of the components of advanced pressurized water reactor systems. It imports the remaining 30 percent, largely the stainless steel pipes, condensors, and other specialty metals needed to meet technical requirements. In general, the Chinese-manufactured components can be up to 30 percent cheaper than imported equipment, although quality may vary and prices in China are rising quickly.

On average, new pressurized and boiling water reactors in China have capital costs of $1,810 per kilowatt. China hopes to localize these technologies and thus bring costs down to about $1,450 per kilowatt within a decade.

Renewable Energy Power Generating Technologies

Hydropower

China has embarked on an ambitious hydropower development program in an attempt to diversify power generation. As in the coal-fired power sector, China has the capacity to produce almost all of it's own equipment, although manufacturing backlogs exist in some sub-sectors.

There are environmental impacts that need to be addressed more thoroughly before deciding to construct large hydropower plants. Some of these considerations are the mass resettling of families, the threat of catastrophic structural failure, the loss of tourism and recreational potential, the impact of silt buildup, the loss of agricultural land, the runoff of pollution into the reservoir, the effects on local flora and fauna, and decommissioning the dams. Other positive benefits related to hydropower plant construction, including flood control and improved navigation, also need to be considered.

Even though China is able to manufacture all but the largest hydropower turbines domestically, construction is capital intensive and expensive. Current capital costs for hydropower turbines range from $950 per kilowatt to over $1,200 per kilowatt. Total project costs can be much higher. The Three Gorges Project, although not designed solely as a power project, is estimated to cost approximately $1,600 per kilowatt.[77] In some cases, several small dams can provide as much electrical output as a large dam, but without the extraordinary environmental impact.

Mini-hydro

Mini-hydropower plants typically rely on run-of-the-river configuration and do not require reservoirs. While this eliminates many of the environmental impacts of larger dams, it also makes the dam subject to low availability in the dry season. Capacity factors for most mini-hydropower stations in western China are only about 30 percent.

China has a long history of manufacturing small and mini-hydro turbines. Capital costs are lower than the larger units, approximately $850 per kilowatt.

Wind Farms

China has reserves of 253 gigawatts of wind power, much of it in Inner Mongolia, Xinjiang and coastal regions. Capital costs, currently around $1,000 per kilowatt or less, are dropping rapidly. Large wind farms in developed countries may soon cost as little as $750 per kilowatt and have levelized costs below $0.05 per kilowatt-hour.

One of the large barriers to greater wind use for base load power is low capacity factor. Wind is not a dependable resource. One way to overcome this limitation is by using storage devices which can continue producing power for the grid even when the wind is not blowing. In many areas of China where world class winds are available, there are water shortages preventing its use as a storage medium. Compressed air energy storage or flywheels might help overcome the poor capacity factor of many wind sites in these water-poor regions.[78]

China currently has less than 100 megawatts of wind power capacity installed, primarily in Xinjiang, Inner Mongolia and Guangdong province. Wind installations will accelerate over the near term. The World Bank and China announced a plan in March 1998 to develop 190 megawatts of new wind capacity at 4 sites during the first half of 1999.[79] Total capacity should reach 400 megawatts by the end of the century. While the largest wind turbines are currently 750 kilowatts per unit, China has not yet been successful in producing its own medium and large size units. The government plans to introduce foreign licensing of wind turbines to help lower manufacturing costs. Large wind turbines mass produced in China could make this power source competitive in some areas with coal-fired units.

By the start of 1996, there were over 72 million people in rural areas still not connected to the grid. Electricity demand for these people will be satisfied by developing new energy technologies because grid expansion is too slow and expensive. More than 140,000 mini wind turbine (60-200 watt) units operate in China, of which more than 110,000 are located in Inner Mongolia. The annual production of mini wind turbines exceeds 21,000 units in this region. Government forecasters estimate the total installed capacity of mini wind turbines will be 30 megawatts in 2000 and 140 megawatts in 2020 with total power generation of 90 and 450 gigawatt-hours, respectively.[80] In appropriate areas, decentralized wind power stations over 10 megawatts will be built and hybrid wind/diesel or wind/solar systems will be developed.

Photovoltaics

Photovoltaic cells convert solar energy directly into electricity. Once used only in space because of their high costs, PV cells are found everywhere today from watches and calculators to irrigation pumps and rooftop power supplies. Costs are dropping rapidly from today's level of approximately $4,500 per kilowatt. Benefits of photoelectric power include high reliability, low construction and operating costs, modularity, and low pollution. Multinational petroleum firms such as British Petroleum and Shell are investing heavily in PV production facilities. About 3 megawatts of PV cells are currently in use in rural China. New thin-film PV cells will have lower costs, greater efficiency, and longer life than traditional silicon-based cells, making them priority research topics for Chinese scientists.

Biomass

Biomass already plays an enormous role in China's rural economy: farmers burn it for heat, plow it into fields to improve soil quality, and feed it to their livestock. There are two types of technology for generating power using biomass: direct combustion and gasification. Direct combustion systems operate much like coal-fired units that use steam turbines to produce electricity in a steam cycle. In developed nations, most biomass plants are used in combined heat and power systems. Designs are moving away from simple grate systems to fluidized bed and circulating bed systems. These units can handle a wide range of feedstock quality.

In modern gasification systems, part of the feedstock is heated in the presence of steam to convert the remaining biomass to gases and organic vapors. After cleaning, these gases are used in turbines to produce power. Like combined cycle turbines, biomass gasification systems do not need to rely on large units to achieve economies of scale. Biomass gasification systems are just entering the commercialization stage.

China has the potential to rapidly develop key biomass technologies that could double conversion efficiencies and make biomass an attractive source of energy for both industrial and utility applications in rural areas. Gas and combined cycle turbines, as well as gasification processes, require additional development of China’s infrastructure to support them.

Other Sources

China will continue to exploit geothermal heat sources to generate power in Tibet and Yunnan. While geothermal plants are competitive in these regions, limited heat supplies prevent us from considering this source further in this study. A number of other technologies including tidal, ocean thermal gradient, and solar thermal power exist and China will probably continue to develop these sources as appropriate. Limited supplies or other technical and financial barriers will inhibit wide-scale application in China, and so are beyond the scope of this study.

5. Modeling Least-Cost Power Generation

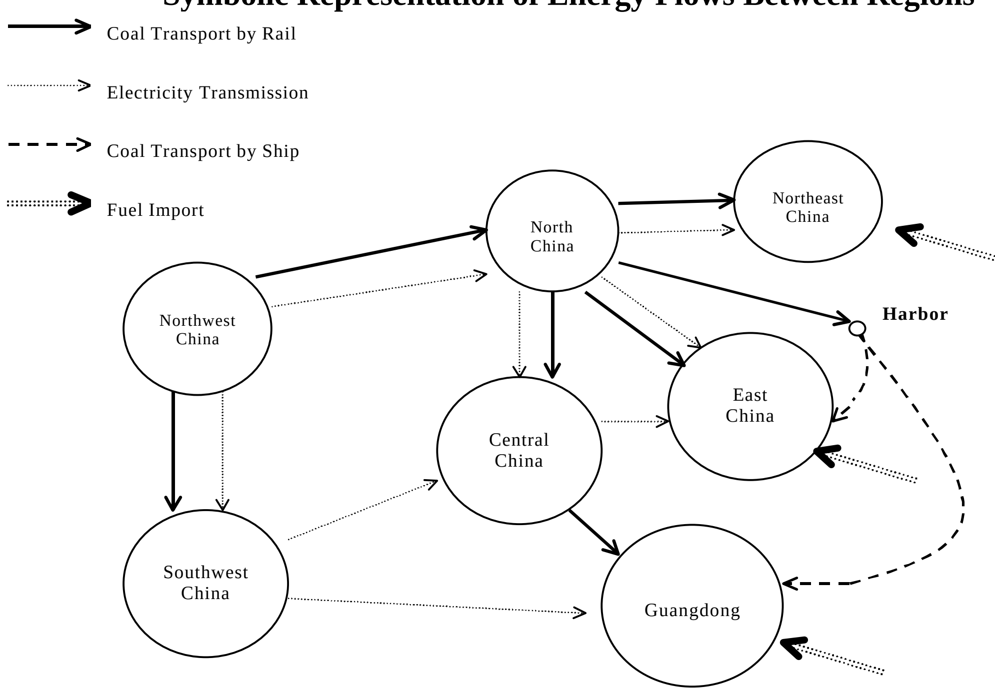
The Linear-Optimization Model

This section describes the EFOM-ENV (Energy-Flow Optimization Model/Environment) model used by the Energy Research Institute in this study. The model integrates the economic trends driving demand with the technological characteristics of energy systems to estimate the least-cost way of meeting China's future energy demand. EFOM-ENV was developed by a European consortium in the 1970s. It was modified by the Asian Institute of Technology in 1995 to optimize electricity generation and transmission among the seven regions of China. The software uses linear programming to analyze the energy producing and consuming sectors of each region. It estimates the development of these sectors under optimum conditions given fuel import prices and energy demand assumptions. Choices are constrained by availability of capital, fuel prices, availability of fuel and transportation limitations, penetration rates of certain technologies, environmental pollution standards, and emission ceilings.

Modeling Energy Flows

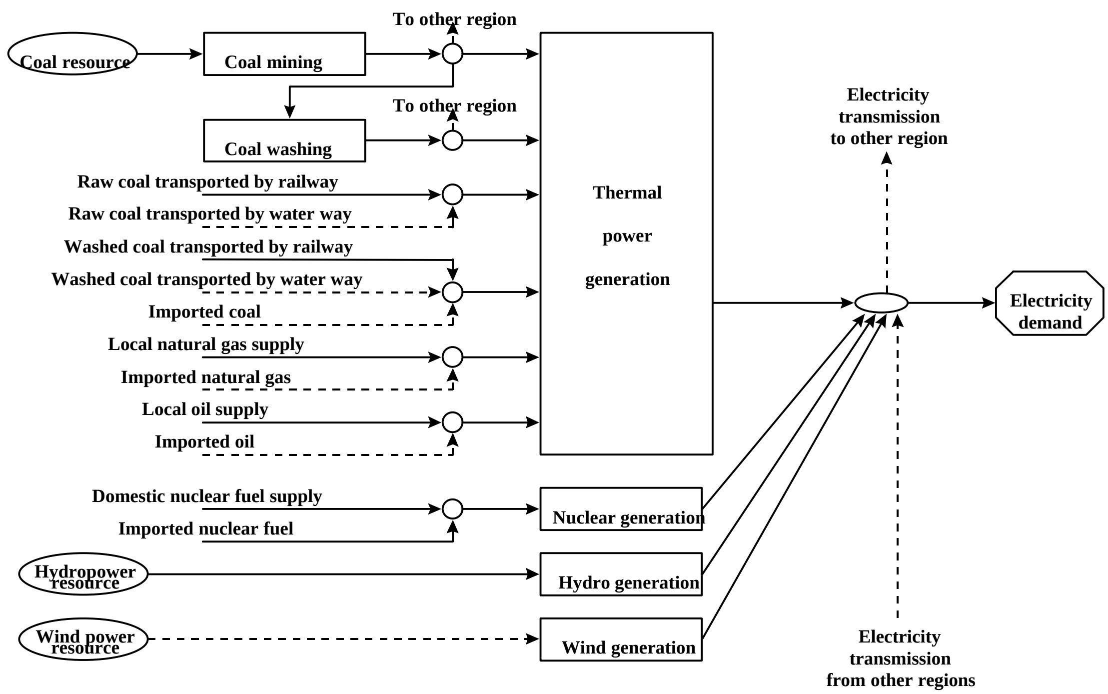
We model future inter-region energy flows by allowing fuel and power to be transported among regions. (See Figure 5.1.)

Figure 5.1
Symbolic Representation of Energy Flows Between Regions



Within each region, we model the entire power generation system. (See Figure 5.2.) Because coal-fired power predominates, and coal transportation and coal processing significantly affect power production and emissions, we describe coal in greater detail--mining, transportation, and technology.

Figure 5.2
Energy Flow Inside a Region



Solid lines describe general energy flow relations inside a region, while dashed lines are optional situations for a region. The model disaggregates fossil fuels in order to provide detailed treatment of pollution issues. Categories include oil, gas, raw coal, and washed coal by region, conventional (small and large size) steam turbine units (both subcritical and supercritical steam units), IGCC, PFBC, and combined cycle gas turbines. All new coal-fired power plants in China are required to have electrostatic precipitators to remove particulates, and so this technology is automatically included. We include as options dry and wet flue gas desulfurization and combined sulfur and nitrogen control technologies. A specific thermal generation technology can be modelled as one specific generation technology and possibly one specific pollution control technology.

Biomass energy has not been included in the model since researchers at ERI do not believe it will have a significant impact on power generation mix before 2020. Reasons for this skepticism include difficulty in collecting, transporting, and storing large volumes of biomass, and because higher overall efficiencies can be gained by using biomass as a fuel for industrial and agricultural process heating, space heating and cooking rather than for power generation. Biomass gasification could eliminate the latter barrier. Fuel cells have also been omitted from the model due to uncertainties in future capital costs, performance, and fuel sources and costs.

Optimization Routine

The EFOM-ENV model is driven by exogenous energy demand assumptions and assumed resource, environmental, and policy constraints. With these inputs, the model simulates and optimizes primary energy requirements and investments in energy production and energy consumption using various energy conversion processes. It has been applied to energy and environmental analysis and planning for all European Union member countries and for developing countries including China, Thailand, Indonesia, and the Philippines. EFOM-ENV has a flexible model structure and can be adapted to local conditions or changing study requirements. The model structure can be represented in greater or lesser detail.

EFOM-ENV contains an energy-environment database describing the energy system being studied. Technologies are explicitly represented by parameters for economic, social, and environmental conditions and linkages among energy systems. Linear programming optimizes the energy system according to an objective function defined by model users.

The energy database provides the model with quantitative information on energy system structure, technology status, investment and other costs as well as pollutant emissions. By creating a specific database for China's regional conditions, and by defining constraints, the model creates an optimization problem that EFOM-ENV solves in the least-cost manner.

For a full mathematical description of the linear programming section of the model, see the Appendix.

Basic Input Data

Base Year Electricity Generation

Electricity generation in the model for each of the seven regions in 1995 is benchmarked to 1990 and 1995, referred to as the reference and base years, respectively. (See Table 5.1.)

Fuel cost

Coal: Coal prices were heavily distorted in the early part of the 1990s, with state-owned mines selling coal priced at only half that of local mines. Coal prices have declined in recent years after peaking in the early 1990s. Now, township and village enterprise and private coal mines sell coal at a much lower price and can compete with state-owned coal mines.

Table 5.1
Reference and Base Year Electricity Generation by Region (TWh)

	1990			1995		
	Total	**Hydro**	**Thermal**	**Total**	**Hydro**	**Thermal**
North	107	2	106	166	3	163
Northeast	91	9	82	122	13	109
East	168	148	153	283	24	256
Central	98	39	59	151	48	102
Guangdong	34	8	27	82	13	58
Southwest	70	33	37	121	62	59
Northwest	49	16	25	65	17	47
Total	621	127	495	1,007	187	801

Sources: 81, 82

The model generates coal prices based on our analysis of recent investment in coal mining capacity in each region and calculations that incorporate investment, labor, taxes, and profits. Investment costs vary with local geological conditions and labor costs vary with local economic development levels, therefore the share of investment costs and labor costs differ by region.

Coal production costs increase with mining depth. Over the study period, costs increase as a function of increasing depth, based on historical trends. (See Tables 5.2 and 5.3.) These estimates account for the projected efficiency gains as small, inefficient mines are closed.

Table 5.2
Production Costs of Raw Coal

		North	**Northeast**	**East**	**Central**	**Guangdong**	**Southwest**	**Northwest**
Heating Value	**(GJ/ton)**	**23.0**	**18.8**	**23.0**	**20.9**	**18.8**	**20.9**	**20.9**
Production Cost ($/ton)	1995	14.5	14.5	18.1	13.9	12.1	12.1	12.1
	2000	16.3	16.3	19.9	15.7	13.3	13.3	13.3
	2005	17.5	17.5	21.7	16.9	14.5	14.5	14.5
	2010	19.3	19.3	24.1	18.7	16.3	16.3	16.3
	2015	21.1	21.1	26.5	20.5	18.1	18.1	18.1
	2020	23.5	23.5	29.6	22.9	19.9	19.9	19.9

Source: 83

Table 5.3
Production Cost of Washed Coal

		North	Northeast	East	Central	Southwest	Northwest	Import
Heating Value	**(GJ/ton)**	**27.2**	**26.4**	**26.4**	**26.4**	**26.4**	**26.4**	**27.2**
Production Cost ($/ton)	2000	26.9	30.8	34.4	28.2	24.6	24.6	44.0
	2005	28.5	33.7	37.0	30.0	26.4	26.4	47.6
	2010	30.9	36.7	40.5	35.3	29.1	29.1	51.9
	2015	33.3	39.6	44.1	37.2	31.7	31.7	56.7
	2020	36.6	43.5	48.6	38.8	34.4	34.4	61.5

Source: 84

In Guangdong and the northeast, east, and central regions, local coal production is limited and coal transport from the north and northwest is required. The model incorporates coal transportation costs from the northern coal production base, and it includes--or selects--imports when and where they are cheaper. Coal transportation costs in Table 5.4 account for the expense of new rail construction required to link future supply and demand centers.

Table 5.4
Cost of Coal Transportation from Northern Production Base ($/ton)

To	Northeast	Central	Southwest	East		Guangdong	
	by Rail	by Rail	by Rail	by Rail	by Ship	by Rail	by Ship
1995	12.1	9.2	12.1	16.9	14.0	21.7	
2000	12.7	9.7	12.7	17.7	14.7	22.9	18.6
2005	13.3	10.1	13.3	18.6	15.4	23.9	19.4
2010	14.0	10.6	14.0	19.5	16.2	25.1	20.4
2015	14.7	11.1	14.7	20.5	16.9	26.4	21.4
2020	15.4	11.7	15.4	22.8	17.9	27.7	22.4

Source: 85

Oil: After decades of subsidies, raw oil prices in China are now generally close to international levels. (See Table 5.5.) Gasoline and diesel prices are now often higher. The average 1995 fuel oil price for power generation was $17.2 per barrel, almost one-third higher than the world average. (See Table 5.6.) Oil prices vary by region, source, quality, and by type of power plant.

Table 5.5
International Oil Price Comparison, 1995
($/barrel)

	China	World Market	United States
Raw oil	13.7	15.7-18.0	16.8
Gasoline	42.9-47.5	21.1	50.9
Diesel	36.4-38.7	19.7	46.4

Source: 86

International prices for petroleum declined rapidly in late 1997 and early 1998. The domestic price for oil has remained relatively constant, however, increasing the pressure to import more crude. In 1997, crude oil imports jumped almost 50 percent from 23 to 34 million tons.[87]

Table 5.6
Price of Fuel Oil for Power Generation by Region, 1995

Region	Fuel Oil Price ($/barrel)
Northern	10.1-15.3
Northeast	12.1-14.8
East	16.9-20.0
Central	14.8-17.7
Southwest	13.5-14.8
Northwest	12.5-15.3
Guangdong	18.3
Total average	17.2

Note: There are approximately 7.5 barrels per ton of Chinese fuel oil.
Source: 88

Chinese experts project fuel oil prices to remain higher in China than the world average until 2010, though the difference should diminish by 2020. (See Table 5.7.)

Natural Gas: Only 1 percent of China's total natural gas consumption in 1995 was used for power generation. Currently, only one large natural gas combined cycle system operates in China, the 2.5 gigawatt Black Point power plant in Hong Kong. Gas is delivered via a 500 mile undersea pipeline. Most other combined cycle systems are either small or operate on other fuels such as distillate or coke gas.

Table 5.7
Fuel Oil Price Projections by Region ($/barrel)

	2000	2010	2020
North	12.9-14.5	13.7-16.9	14.5-19.3
Northeast	12.5-15.7	13.7-16.1	14.5-19.3
East	17.7-20.9	17.7-20.9	18.5-20.9
Central	17.3-20.1	15.7-19.3	16.1-19.5
Southwest	15.3-18.5	15.3-16.9	16.1-20.0
Northwest	14.5-16.1	13.7-16.9	14.5-17.7
Guangdong	18.4	19.3	20.7
Total average	17.5	19.2	20.3
World average	14.7-16.0	17.3-18.7	20.0-21.3

Source: 89

The average 1995 gas price was $1.58 per GJ, except in Sichuan where it was slightly lower. The government still allocates a large fraction of gas to the fertilizer sector and subsidizes its use. To boost supplies, gas prices would have to rise to give producers more incentive.

Table 5.8
World Natural Gas Price Projections ($/GJ)

	1995	2000	2005	2010
U.S. (well-head) 1998	1.9	2.0	2.1	2.2
Europe (imported) 1995	2.3	2.5	3.6	3.6
Japan (imported LNG) 1995	3.6	3.7	5.4	5.4

Sources: 90, 91

United States forecasters recently projected that natural gas prices will rise more slowly than previously thought. (See Table 5.8.) It is likely, therefore, that projected prices for Europe and Japan will also be revised downward.

Delivered prices for imported pipeline natural gas are comparable to World Bank estimates for the first two Russian sources listed in Table 5.9, but higher than Bank estimates for the remaining three.[92] Prices for locally produced gas estimated by the Energy Research Institute are comparable. (See Table 5.10.)

Table 5.9
Estimated Prices for Imported Pipeline Natural Gas in China

From	To	To	To	To	Cost ($/GJ)
Sahalin	Daqing	Shenyang			3.26-3.39
Irkutsk	Beijing	Rizhao	Shanghai		3.39-3.63
New Siberia	Urumuqi	Xi'an	Shanghai		4.25-4.38
Kurle	Shanshan	Xi'an	Shanghai		4.25-4.38
Wanxian	Zhijiang	Wuhan	Changsha	Guangzhou	4.60

Source: 93

Estimating future natural gas prices is a difficult task. In 1992, for example, the U.S. Department of Energy's *Annual Energy Outlook* forecast well-head gas prices of $4.38 per GJ for 2010. Over the following years, it revised the 2010 estimate to $3.34 per GJ (1993), $3.06 per GJ (1994), $2.93 per GJ (1995), $1.81 per GJ (1996), $1.88 per GJ (1997) and $2.16 per GJ (1998). While China's gas sector is much different from that in the United States, it is likely that price forecasts will decline after prices initially rise and more gas is discovered. A 1995 study by the China National Offshore Oil Corporation and Atlantic Richfield Corporation estimated LNG prices from $3.18-3.55 per GJ and South China Sea natural gas prices of $3.51 per GJ in 2010 in Guangdong and Guangxi provinces.[94]

Table 5.10
Natural Gas Price Projection by Region ($/GJ)

	2000	2010	2020
North	1.85-3.39	2.78-3.86	3.39-4.63
Northeast	1.85- 2.46	2.62-3.71	3.08-4.01
East	1.85-3.08	2.78-3.86	3.08-4.63
Central	2.46-3.39	2.62-3.71	3.08-4.01
Southwest	1.85-2.46	2.01-2.78	2.46-3.39
Northwest	1.85-3.08	2.46-3.71	3.08-3.71
Guangdong	1.85-2.92	2.46-4.01	3.08-4.63
Total average	1.85-3.08	3.08-3.71	3.08-4.32
World average	3.32	3.59	3.84

Source: 95

Investment costs

Capital investment costs for power projects are based on 1995 values, the base year of all calculations for the model. Because many factors affect these estimates, we use statistically averaged data from the years 1994, 1995, and 1996.

This study includes certain emission control and advanced generation technologies that have not yet been commercialized. In those cases, cost data are based on the literature. To make Chinese and international data compatible, some modifications have been made and are explained below. (See Table 5.11 for a summary of investment cost estimates.)

Conventional Coal-Fired Power Plants: The average capital investment cost for coal-fired power plants equipped with 300 megawatt units and above was $403 per kilowatt in 1994, $510 per kilowatt in 1995 and $551 per kilowatt in 1996. To allow for likely increases in capital costs in the future, we estimated the capital cost of coal-fired, subcritical units at $603 per kilowatt. However, the reader should note that an even higher price of $660 per kilowatt could be justified on the basis of rapidly rising prices and the difficulties of manufacturing boilers and turbines. Sensitivity tests were run to account for such possibilities.

Because only a few supercritical steam generation units have been used in China, the cost data for this type of system are limited. China is still unable to completely manufacture the metals and technologies required in a large, supercritical steam unit, and must rely on expensive imported components. These imports could result in a total capital cost 10-20 percent higher than the subcritical units. To be conservative, which is to say not biased against the status quo, we used the lower figure.

Flue Gas Desulfurization: At present flue gas desulfurization is not widely used in China. FGD will increase total power plant investment by 15-25 percent, or about $100 per kilowatt for dry and $150 per kilowatt for wet scrubbing technologies, respectively.[96] In our calculations, we used dry FGD capital costs of $85 per kilowatt and wet FGD costs of $138 per kilowatt. In a sensitivity test, we also modeled a combined sulfur/nitrogen oxide removal technology with capital costs of $163 per kilowatt. China would need to substantially accelerate the manufacturing capacity for FGD units if a major sulfur control policy were enacted.

Hydropower: The average investment for hydropower stations has been about $1,000 per kilowatt until recently. Large plants are becoming more expensive, however, especially when their functions include flood control and shipping improvements. Allocation of capital investment costs is difficult to do precisely. Small and mid-sized hydropower stations average $843 per kilowatt while mid-sized and large stations--normally far from load centers and in rugged, isolated terrain--are difficult to construct and cost more on the order of $1,324 per kilowatt.

Nuclear Power: No data are available on the capital costs of nuclear power plants using Chinese technology. Chinese reactors undoubtedly cost less than foreign ones built in China, which have averaged about $2,000 per kilowatt. (See Table 4.7.) We assume capital investment costs of $1,810 for plants to be constructed before 2005. Thereafter, we assume that China would be able to domestically manufacture all the equipment and components for an advanced nuclear power plant. Capital costs would then decline to

$1,445 per kilowatt, lower than the world average. In an advanced technology scenario, we assume costs drop further to $1,200 per kilowatt.

Other Generation Technologies: China has imported combined cycle gas turbines and wind turbines in recent years. In our calculations, we use international prices for these technologies in the pre-2005 period. After 2005, we assume that domestic manufacturing capability for these technologies will improve and capital costs will decline. In a policy scenario where the government initiates an accelerated development scenario, capital costs could decline dramatically.

IGCC and PFBC technologies have not been commercialized at the time of this study, but China is working with the U.S. Department of Energy and private businesses to develop them. Cost estimates vary widely, but first generation units will be more costly than units that are deployed on a mass scale. We have taken average capital costs from the literature.[97]

Long Distance Transmission: Capital costs for long distance electricity transmission depends on power type (AC or DC), distance, number of lines, and materials used in both sending and receiving systems. This function is complex and non-linear, but we have simplified the relationship in our modeling. That is, we have used a simple linear relationship between capacity and cost.

Transmission lines of 500 kV and over in 1995 cost $178,000 per kilometer. Transformers added $67/kVA. We assume AC transmission for distances less than 600 kilometer, and DC transmission for longer distances. Capital costs for transmission lines are thus $181,000 per kilometer, AC transformers $36 per kilowatt, and DC converter/inverters $157 per kilowatt. (See Table 5.12.)

Environmental Externality Costs

Research on evaluating the external environmental costs of power generation in China is focused on evaluating the impacts of single pollutants in limited areas. There are no commonly accepted methodologies and little data to support qualitative analysis over a large region.[98]

In this study, we ran several scenarios with approximated environmental externalities to see how they affect technology choices in the optimization routine. Quantitatively, we concentrate on SO_2 emitted by coal-fired power plants. While other pollutants such as particulates, nitrogen oxides, heavy metals, solid wastes and damages to human and natural ecosystems should be valued, we focus on sulfur here for the following reasons:

- SO_2 is one of the most damaging pollutants in China. It causes acid rain in many regions, resulting in tremendous ecological and economical harm.
- Other air pollutants from power plants--particulates, for instance--are or will soon be under control now that electrostatic precipitator devices are required on all new power plants. They are less harmful in a power plant environment than similar pollutants

emitted from industrial boilers and household stoves.

Table 5.11
Capital Investment for Generation Technologies

Technology	Investment ($ per kilowatt) Import	Investment ($ per kilowatt) Domestic	O&M Cost ($ per kilowatt/yr)	Efficiency (%)	Lead time (year)
Subcritical Coal-Fired Units		603	18	37	2
		663*	23*	36*	
Supercritical Coal-Fired Units		663	20	38	2
		724*	25*	37*	
IGCC	1,327	1,025+	29	43	2
PFBC	1,327	1,025+	23	40-42	2
Conventional CCGT	603	543	20	40	1
			15*	45*	
Advanced CCGT	850	603+	25	50	1
			17*	55*	
Nuclear Power	1,810	1,448+	47	33	7
Large Hydropower		1,327	20		9
Small Hydropower		844	9		5
Wind Turbines	1,206	844+	18		1
	1,000*				
Dry FGD		84	5*	60**	
Wet FGD		139	10*	90**	
Flue Gas Scrubber		163+	10*	90**	

* PNNL estimates.
\+ Available after 2005.
** Desulfurization efficiency.

Regarding the highly unbalanced population, socio-economic development levels, and pollution situation, we use different external costs for different regions. Two groups of externality sets have been developed. The first set was based on a recent World Bank study that estimated power plant SO_2 damage near Shanghai at $390 per ton of sulfur dioxide. Externality values for other regions were adjusted according to differences in per capita income and local sensitivity conditions. We generated the second set of externality estimates based on a number of domestic studies.[99] (See Table 5.13.)

Table 5.12
Capital Costs for Long-Distance Transmission

	Distance (km)	**Investment** ($ per kilowatt)
North to Northeast	1,000	338
North to East	600	226
North to Central	500	196
West to North	200	89
West to Southwest	600	226
Southwest to Guangdong	1,000	338
Southwest to Central	1,000	338
Central to East	800	286

Source: 100

It must be noted that these externality values are only approximations and we use the two different sets to model the estimated extremes. While general guidance is found in publications by the World Bank[101] and Xu Xiping,[102] a more satisfactory study would include the external costs of river productivity losses; land use impacts of hydropower; risks of nuclear power; land use and agricultural impacts of biomass; land and water impacts of mining; and the health effects of fine particulate emissions.

Table 5.13
Externality Costs for Sulfur Dioxide Emissions ($ per ton of SO_2)

	North	**Northeast**	**Northwest**	**Southwest**	**Guangdong**	**East**	**Central**
Upper	362	362	181	724	965	965	724
Lower	302	338	157	181	470	398	205

6. Least-Cost Analysis

This section presents results from five scenarios created to analyze different policy options. The scenarios include baseline, sulfur control, carbon dioxide control, natural gas policy, and advanced technology development options. The natural gas policy scenario, for example, shows how the penetration of gas-based technologies varies with natural gas price and capital costs. These prices are, in turn, dependent on policies and regulations enacted by the government.

Results include both the amount of power that each type of power supply would produce while constrained to meeting the least-cost objective function and the actual capital, fuel and operating costs. We begin the section by presenting the power generation mixes for each scenario and close with a summary of the total costs.

Several potential power generation technologies assessed in Section 4 are not included in the modeling results. Biomass energy was not included in the model for reasons mentioned in Section 5. Wind power does not appear in the results because it is not economic under the current modeling assumptions. Fuel cells were also not included in the model due to future cost uncertainties. A number of common assumptions hold for each of the scenarios.

Basic Assumptions

We assume that all large hydropower stations planned for completion before 2010 are under construction and will be completed. Hydropower stations planned after that date, however, are subject to the model's economic constraints. The hydropower capacity that can be exploited in the southwest region by 2020 is limited to 50 percent of the total potential. In other regions, the maximum is set at 80-90 percent of potential.

The model constrains coal use for power in the northeast and east to 70 percent of production, and in Guangdong to 50 percent. The model allows coal to be supplied to Guangdong from Guizhou, and to all regions from the north and northwest. The amount of coal supplied is limited not by production capacity but by transportation capacity.

The model selects the cheapest fuel sources from local and imported supplies. Fuel prices reflect average local production costs and average transportation costs. For example, coal prices reflect costs to construct coal supply and transport infrastructure. (See Tables 5.2-5.4.) Capital costs for power generation and transmission equipment are discounted at a real rate of 12 percent. There are no constraints on pollutant emissions and no external environment costs involved in baseline calculations and optimization. (Note that abbreviations for types of power supply technology used in the following sections are listed in Table 6.1.)

Table 6.1
Definitions for Power Supply Technologies Used in the Modeling

Definition	Meaning
Existing Coal	Existing coal-fired units
New Subcritical	New subcritical steam (<24 MPa) coal-fired units without FGD
New Subcritical Low	New subcritical coal-fired units with low-efficiency FGD (dry scrubbers)
New subcritical High	New subcritical coal-fired units with high-efficiency FGD (wet scrubbers)
New Supercritical	New supercritical steam (>24 MPa) coal-fired unit without FGD
IGCC	New integrated gasification combined cycle
PFBC	New pressurized fluidized bed combustion
CC	New conventional combined cycle gas turbine units
Adv. CC	New advanced combined cycle gas turbine units
Existing Hydro	Existing nuclear power units or those under construction
New Nuclear	New nuclear power generation units
Existing Hydro	Existing hydropower units
New Hydro	New and planned hydropower generation units
Wind	New wind turbine units

Note: New supercritical steam coal fired plants with low- and high-efficiency FGD were also considered but found uneconomical in the analysis.

Baseline Scenario

A baseline scenario with no environmental constraints was developed in order to serve as a context for comparison with other cases. The baseline scenario is a static view of China's future because it assumes technologies, costs, energy supplies, and policies will remain as they are today. In this sense, it should not be considered a "business as usual" scenario because China will most likely utilize more efficient technologies and enforce stricter environmental control measures. Indeed, if the baseline case were actually achieved, sulfur emissions alone would be devastating in some regions.

The least-cost combination of electricity generating technologies for the baseline case shows that coal-fired plants without FGD could supply almost 85 percent of the country's electricity with hydropower making up most of the remainder. (See Figure 6.1.)

The baseline case assumes that huge volumes of coal can be transported. The amount of coal transported from the north to the centers of consumption increases steadily to over 330 million tons by 2020. (See Table 6.2.)

Table 6.2
Coal Transportation from North Region in the Basecase
(million tons of coal equivalent)

Year	2000	2005	2010	2015	2020
To Northeast	28	25	25	12	0
To Guangdong	15	13	5	0	.3
To East	65	86	97	157	228
To Central	4	8	36	63	104
Total	112	131	164	206	332

The amount of coal transported from the north to the east will more than triple to 228 million tons of coal equivalent by 2020. The central region will also rely on growing quantities of northern coal. Similarly, power sent from energy surplus areas to the east and south also increases steadily. The amount of power sent from the southwest to Guangdong is projected to increase eight-fold. (See Table 6.3.)

Table 6.3
Power Transmission in the Basecase (TWh)

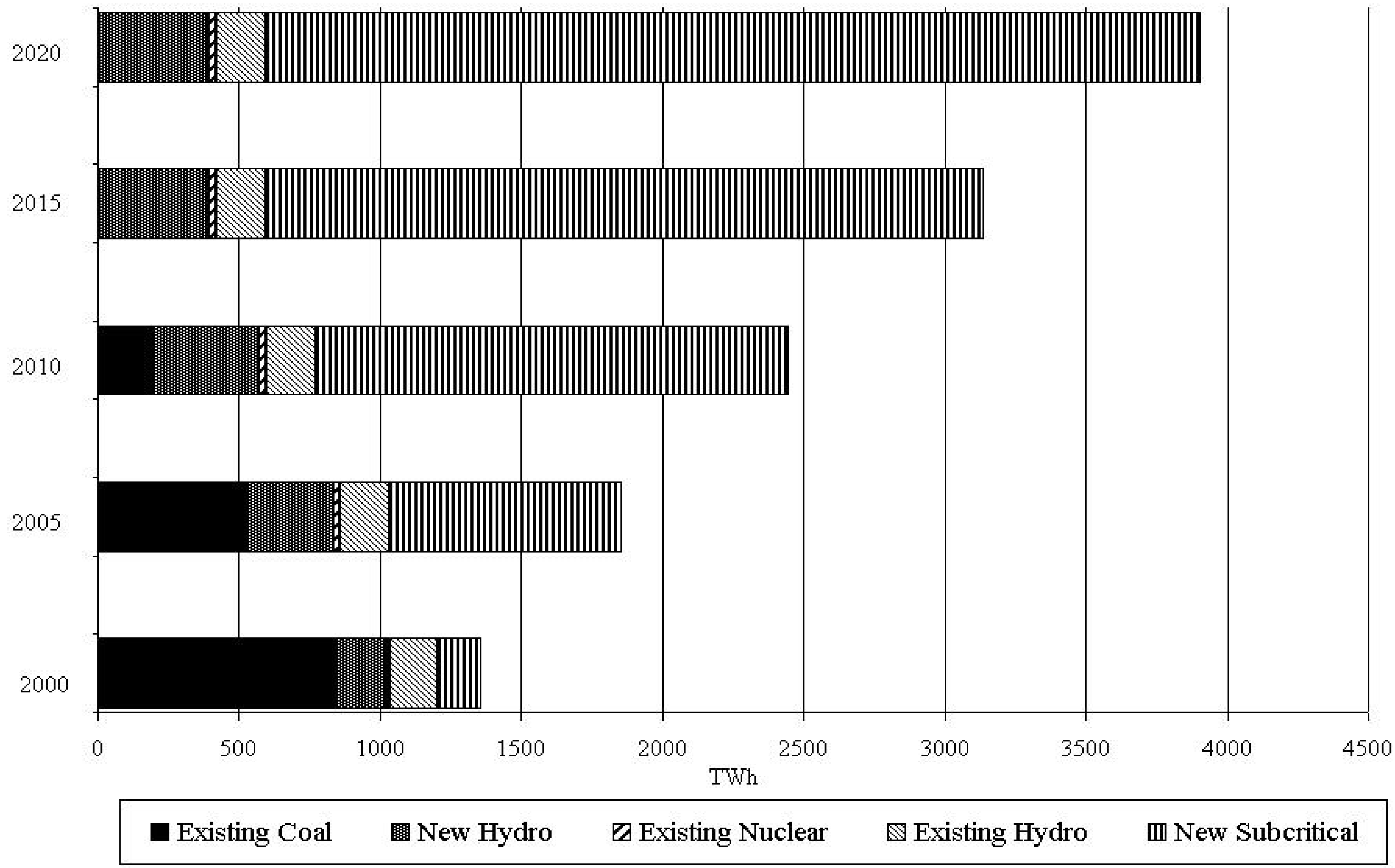
From	To	2000	2005	2010	2015	2020
North	East	21	39	54	54	54
Southwest	Guangdong	36	70	137	204	262
Southwest	Central	6	6	6	6	0
Central	East	6	6	63	63	63

Cumulative capital investment costs over the period 1995-2020 amount to $492 billion. The total costs of this scenario and the other four scenarios are shown in Table 6.9.

Table 6.4
Capacity Cost by Region: Baseline Scenario ($ billion)

	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020
North	5.7	16.9	19.1	15.3	18.5
Northeast	5.3	10.7	11.1	9.0	10.7
Northwest	5.6	7.5	4.9	5.2	6.9
Southwest	28.5	32.2	15.5	16.8	15.3
Guangdong	1.2	20.0	0.0	0.6	0.0
East	14.6	23.6	19.3	27.0	25.0
Central	18.9	24.7	31.1	11.7	14.7
Transmission	2.5	1.9	5.2	2.7	4.6
Total	82.3	119.4	106.2	88.2	95.5

Figure 6.1
Least-Cost Power Supply Mix, Baseline Scenario



Analysis of Results

Conventional coal-fired power is the least-cost option in the baseline scenario. Even in Guangdong and the east where coal prices are relatively high, coal-fired power generation is still the cheapest technology. Hydropower is less competitive because of high capital investment costs. In a least-cost baseline case, no new hydropower stations would be built after 2010. Note that this scenario does not incorporate environmental externalities. Optimization results show that transmitting electricity from the northern coal base to the east will be cheaper than transporting coal. However, water scarcity will limit electricity generation in the north, restricting transmission capacity in the model to 2.7 gigawatts through 2005 and 6.8 gigawatts from 2010 to 2020. (See Table 6.3.)

Currently, most of the coal used in Guangdong for power generation is imported from the northern coal base by railway or rail-barge combination. Least-cost analysis shows that transmitting coal-fired power from Yunnan in the southwest to Guangdong would be more economical than constructing coal-fired power plants in Guangdong and transporting the coal from the north. Coal production in the central region cannot satisfy the rapid increase in demand for power generation. Electricity transmitted from the southwest region and coal transport from the northern coal base are required, therefore, to satisfy demand in this region. Coal transportation from the northern coal base to the central region would increase rapidly, reaching 100 million tons by the year 2020. (See Table 6.2.)

Guizhou and Yunnan have significant coal resources and could become important coal production bases for southern China. High capital costs handicap hydropower plants even in this water-rich region. While many analysts have suggested speeding hydropower development in this region and sending power where it is needed, constructing transmission lines spanning 2,000 kilometers to east China and 1,000 kilometers to Guangdong may be prohibitively expensive.

In the baseline case, total coal consumption for power generation in 2020 would reach 1.6 billion tons of raw coal, almost 70 percent of total coal production in that year. In 1995, China's power sector consumed about one fourth this amount (400 million tons). Coal transported from the north would total 100 million, 160 million, and 330 million tons of coal in 2000, 2010, and 2020. If coal transportation for other uses does not increase significantly, the planned transportation capacity will be sufficient for interregional coal transportation. Total SO_2 and CO_2 emissions from coal-fired power plants will be 32 million and 820 million tons (carbon), respectively, up over 4 and 3 times from 1995 levels.

Sulfur Dioxide Control Scenario

This section considers sulfur emission controls in four cases as shown in Table 6.5. These controls include both sulfur caps, where sulfur dioxide emissions are restricted by government-set standards, and sulfur dioxide fees, or taxes on sulfur dioxide emissions.

Table 6.5
Sulfur Emission Control Scenario

Case 1	Low Standard	SO_2 emissions limited to year 2000 baseline
Case 2	High Standard	SO_2 emission limits set according to Table 6.6
Case 3	Low Fee	SO_2 fee based on World Bank estimate
Case 4	High Fee	SO_2 fee based on Chinese estimate

In case one, SO_2 emissions in Guangdong and the east, central, and southwest regions are limited to levels no more than the baseline emission level in 2000. There are no limits on SO_2 emissions in the north, northeast and northwest regions. In the second case, SO_2 emissions in Guangdong and the east, central, and southwest regions are constrained as shown in Table 6.6. In this scenario, for example, the eastern region is limited to 43 percent of its year 2000 emissions in 2020. SO_2 emissions in the other regions are limited to year 2000 levels.

Table 6.6
Regional SO_2 Emission Levels in Case 2 of Sulfur Control Scenario (%)*

	2000	**2005**	**2010**	**2015**	**2020**
Southwest	100	66	66	66	66
Guangdong	100	90	81	72	63
East	100	87	77	64	43
Central	100	94	88	82	71

* Taking baseline emission in year 2000 as 100%.

In the remaining cases, we apply fees on sulfur emissions in an attempt to model the effect of "internalizing" the damage done by this class of pollutants. The low sulfur fee applied in case three is derived from World Bank data as described in the text associated with Table 5.13. Case four uses higher fees derived from a number of studies undertaken in China. This case also uses capital cost estimates and technology performance characteristics as defined by PNNL researchers, which are slightly different than those defined by ERI researchers. (See Table 5.11.) This data was used to demonstrate the sensitively of capital cost and technology performance estimates. The sulfur fees used in cases 3 and 4 are approximately an order of magnitude higher than the sulfur taxes currently encoded, although poorly enforced, in some regions of China. Chinese researchers recently revealed that sulfur dioxide emissions cause over $13 billion per year in damage. Given the country's roughly 24 million tons of SO_2 emissions in 1995, unit damage is approximately $515/ton of output. This figure falls squarely within the range of estimates used in the study. In the U.S., those states which have enacted similar sulfur externality fees generally use higher values.[103]

In cases one and two, coal is still the dominant source of energy for electricity generation, but dry and wet scrubbers become the least-cost way of reducing sulfur emissions to the required levels. (See Figure 6.2.) These scrubbers would be needed on over half of all new pulverized coal power plants under the sulfur cap scenarios. New hydropower and nuclear plants do not contribute to the least-cost optimization beyond their baseline values.

In the low sulfur fee case, the least-cost combination of technologies is similar to the low standard case, but even less desulfurization equipment is required. In the high sulfur fee, case, however, over 1,000 terawatt-hours of least-cost electricity will be generated with combined cycle units. This amounts to about 175 large plants (1 gigawatt) over the 20 year period, or bringing on-line 9 plants a year. Each plant would consume approximately a billion cubic meters per year. Huge amounts of natural gas would be needed to make this happen, but the important point is that any amount up to 175 gigawatts would be economically justified. Again, new nuclear and hydropower plants are not part of the least-cost generation mix.

Carbon and sulfur dioxide emissions for the two cases using sulfur fees are shown in Figures 6.3 and 6.4. Carbon emissions are over 100 million tons less per year in the high fee case by 2020. Sulfur emissions, on the other hand, vary much more, with the high fee case leveling off at approximately 10 million tons per year in 2020 compared to the baseline of over 30 million tons.

It is not possible to directly compare the effectiveness of the two sulfur control strategies (caps and taxes) used in the model and state which one is better for China. This barrier exists because the model is not a behavioral one; that is, it does not operate according to the supply and demand behavior defined in microeconomic theory. If the model did account for changes in demand arising from changes in price, we might be able to determine which sulfur control system is better for China.

Sulfur and carbon emissions for the cases using sulfur caps are not available. The modelers had difficulty with the output of these two cases and could not fix the problem before publishing the report.

from electricity generation. Capital cost investments, however, are high for both options, especially considering the long lead time for construction. Even in the most demanding carbon reduction scenario, where emissions must decline by 30 percent from the 2020 baseline level, newly installed nuclear power plants account for less than 3 percent of national demand in the year 2015 and less than 12 percent in 2020. Hydropower also remains below 15 percent by 2020.

Results show that natural gas power generation can play a more important role in mitigation of CO_2 emissions, but this role will depend greatly on the price of natural gas. Combined cycle power generation could deliver up to 31 percent of the nation's power by 2020 at the lowest cost under a carbon control scenario. Maximum natural gas prices of $3.10 per GJ were used in the calculations, notably higher than gas prices in the U.S. and about twice the current cost of gas in Sichuan province. The next section will analyze the influence of natural gas prices on combined cycle systems in China.

Natural Gas Policy Scenario

Natural gas-fired combined cycle systems have developed rapidly in industrialized countries. They are creating more interest in China as a clean, efficient substitute for coal-fired power. Without special environmental and institutional considerations, however, combined cycle systems may have difficulty competing against coal units in many regions of China since coal is so much cheaper and more well-established. Given this, a group of cases have been developed to examine the influence of gas price and capital investment costs on penetration of this technology.

- Baseline: maintain natural gas prices at $2.78 per GJ (0.9 Yuan/$m^3$) through 2020, and set the capital costs of combined cycle gas turbines the same as the baseline case.
- Low-cost capital: maintain natural gas prices at $2.78 per GJ for all years, and reduce capital costs for conventional and advanced combined cycle systems to $362 per kilowatt and $422 per kilowatt, respectively, after 2005.
- Low-cost gas and capital: maintain low natural gas prices at $2.16 per GJ (0.7 Yuan/$m^3$) for all years, and reduce capital costs for conventional and advanced combined cycle systems to $362 per kilowatt and $422 per kilowatt, respectively, after 2005.

The results indicate shifts of coal-fired to gas-fired power of more than 1,000 terawatt-hours are possible in the year 2020 if gas prices and generation technology capital costs can be contained. Environmental benefits would amount to almost 130 million tons of carbon reduction and 15 million tons of sulfur emissions reduction annually by 2020.

Figure 6.8
Least-Cost Power Mix, Natural Gas Policy Scenario

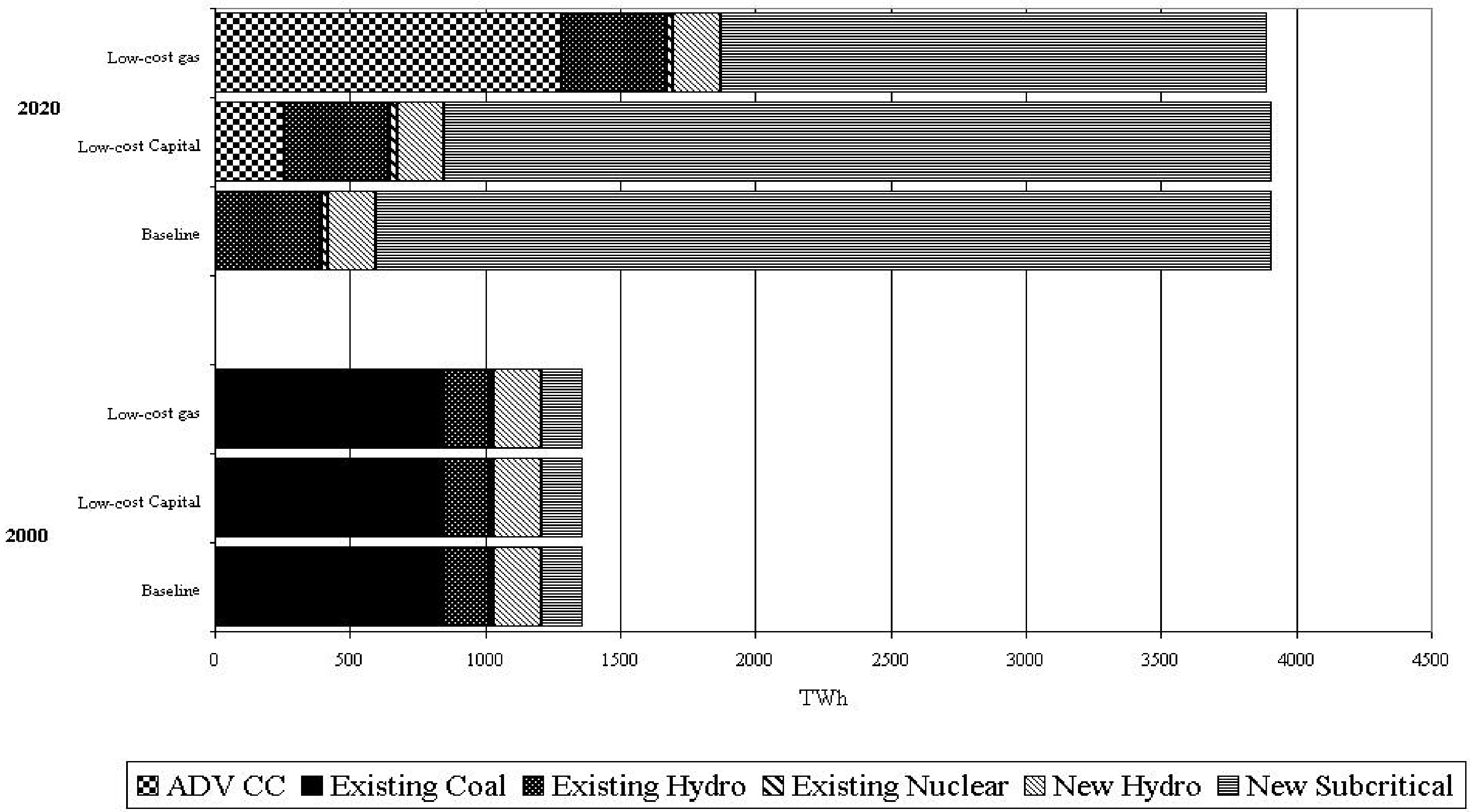


Figure 6.9
Variation of Power Sector CO_2 Emissions Under Natural Gas Policy Scenario

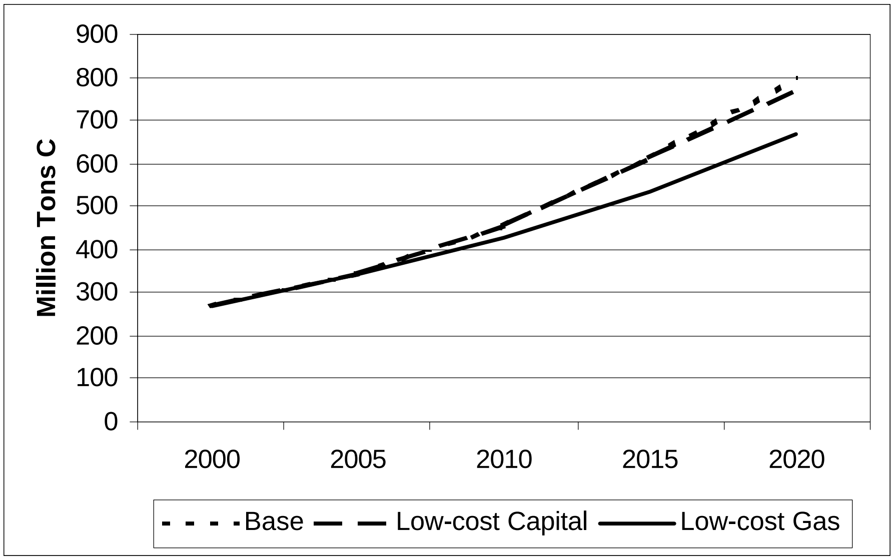
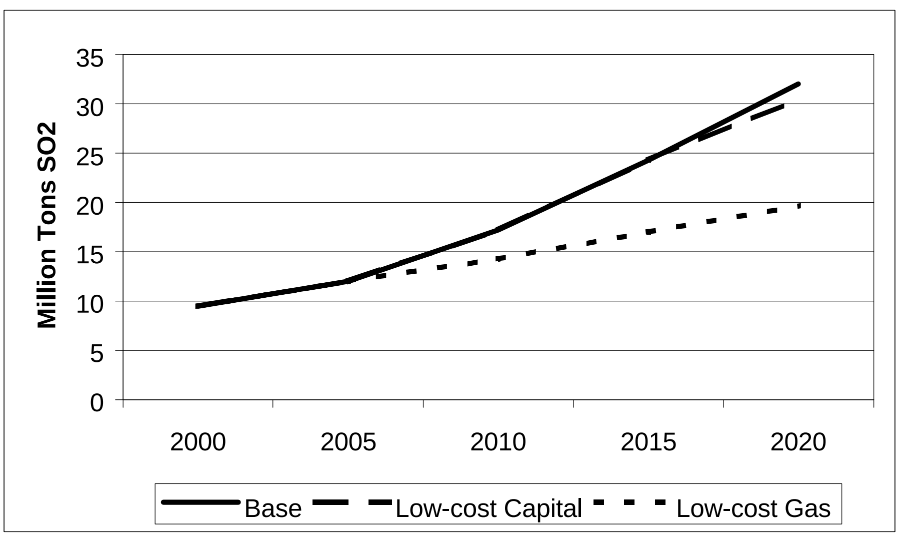


Figure 6.10
Variation of Power Sector SO_2 Emissions Under Natural Gas Policy Scenario



These results indicate that up to one-third of China's least-cost power demand could be met with advanced combined cycle systems by 2020 if gas prices are kept at or below $2.16 per GJ (0.7 Yuan/$m^3$). This price is between the current price for gas in Europe and the United

States. (See Table 5.8.) Two issues may slow the penetration of gas-powered technology into the electricity sector, however: 1) a paucity of gas at the prices required by power generators; and 2) the fact that natural gas' highest value is not in generating power, but in replacing coal combustion in residential, commercial, and small industrial applications where its effect on human health is most damaging.

Regarding gas availability at low prices, Chinese researchers at ERI are less optimistic about the availability of sufficient future supplies than some international forecasters. Estimates from ERI state that gas prices could rise to as high as $4.64 per GJ (1.5 Yuan/ m^3) by 2020. (See Table 5.10.) Historical evidence from the last ten years and current forecasts indicate that gas prices will remain stable or rise slowly over the next 15 years in the United States.[104] Indeed, around the globe, gas supplies are much greater now than anticipated in the 1980s and prices have remained low despite occasional surges. There are, of course, huge differences between China's gas sector and those in other countries, but the general trend of more gas at lower prices than once thought is common across many of them.

Accelerated Technology Scenario

The accelerated technology scenario explores the effect of speeding the development of advanced power generation technologies. We assume that capital investment costs for PFBC, IGCC, combined cycle, and nuclear plants can be lowered by manufacturing them locally, which would be achieved with an accelerated R&D program. Just as China is capable of manufacturing coal-fired power plants approximately 30 percent cheaper than developed countries, we assume that China can rapidly learn how to manufacture these technologies domestically.

Three cases have been developed for this scenario:

- Case 1: reducing the capital cost of hydropower from $1,325 per kilowatt to $1,085 per kilowatt and that of nuclear power from $1,450 per kilowatt to $1,210 per kilowatt; and imposing high fees on SO_2 emissions. (Referred to as "low hydro/nuclear" in Figure 6.12.)
- Case 2: reducing hydropower and nuclear capital costs as above in case 1 and reducing the costs of IGCC and PFBC units from $1025 per kilowatt to $784 per kilowatt. The case would also lower the cost of conventional combined cycle gas turbines and advanced combined cycle units to $420 per kilowatt and $480 per kilowatt, respectively, and would impose high fees on SO_2 emissions. (Referred to as "low all" in Figure 6.12.)
- Case 3: this case uses the same low capital costs as in case 1, and also imposes a cap on sulfur emissions after the year 2000. (Referred to as "low hydro/nuclear and sulfur cap" in Figure 6.12.)

The first two cases are similar except to the extent to which combined cycle power penetrates the market. In case 2, much greater combined cycle power is part of the least-cost solution because capital costs are assumed to drop to $482 per kilowatt by 2005. This is perhaps more feasible given the relatively low requirement of 50 percent efficiency.

Subcritical pulverized coal plants with wet and dry scrubbers make more of an impact in case 3. Supercritical units make a small impact on each of these cases starting in 2005. Case 2 is the only one where PFBC technology made a significant penetration into the least-cost combination of supplies. Nuclear power contributes modestly in both cases 1 and 3.

An identical scenario was created for technology improvements without the sulfur externalities and caps, but the optimization results did not differ from the baseline case so we do not include them here. The results in this scenario show that even under conditions where sulfur externalities are considered and SO_2 emissions are constrained, the application of advanced generation technologies is mainly determined by their economic behavior, rather than their environmental performance.

But when the technologies are economically competitive, their environmental performance will affect their application. This can be found in the results, with the same capital investment, IGCC would be selected in the southwest region because it emits less SO_2 than PFBC and this region's coal has a much higher sulfur content. PFBC would be selected in the other regions since the operational cost of PFBC is a little bit lower than that of IGCC.

These results show that without special environmental constraints, low gas prices will be the key factor for substituting coal-fired power generation with natural gas fired power generation. Over the short term in China, natural gas supplies available for power generation will be very limited, but over the longer term, natural gas availability and price could improve significantly.

Figure 6.11
Least-Cost Power Mix, Advanced Technology Scenario

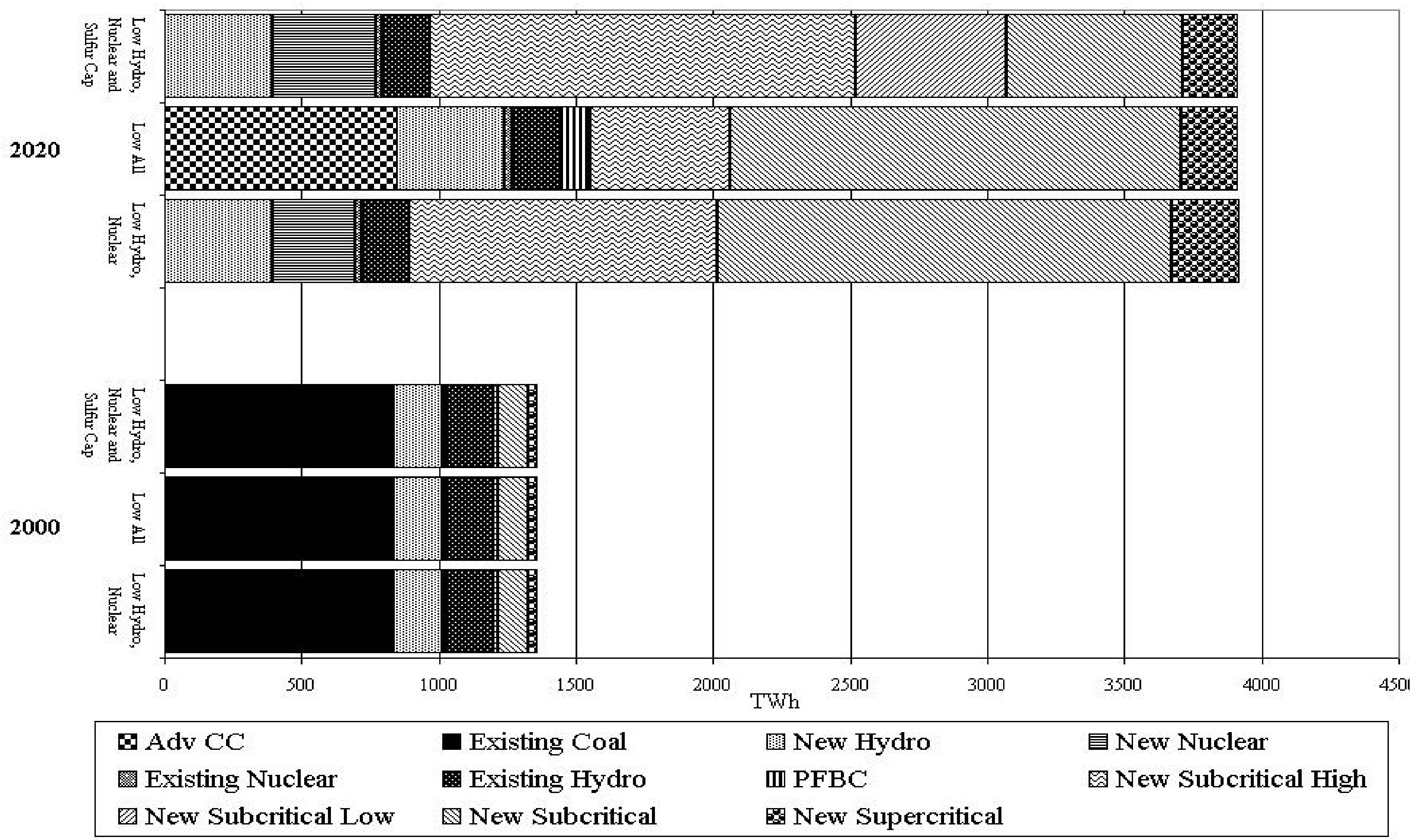


Figure 6.12
Variation of Power Sector CO_2 Emissions Under Advanced Technology Scenario

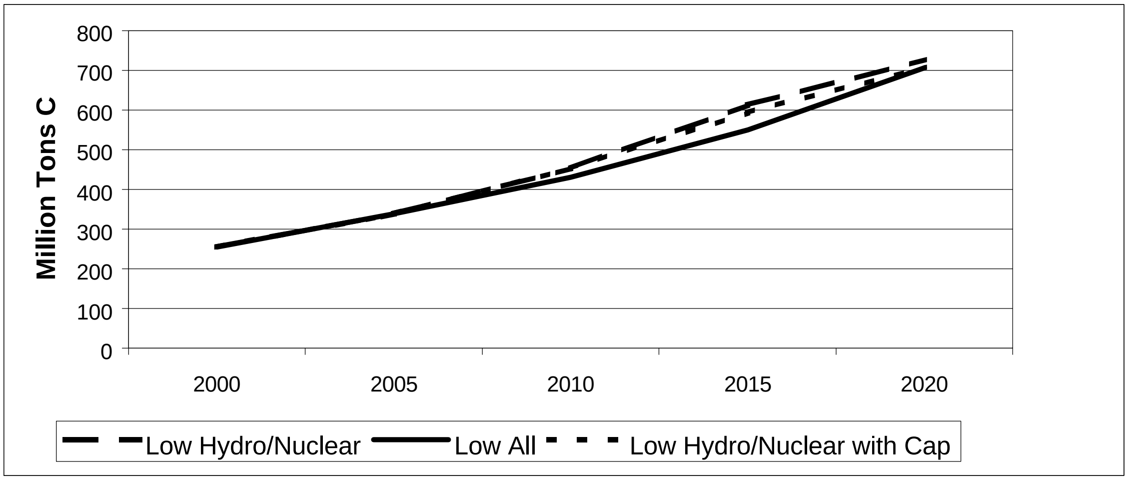
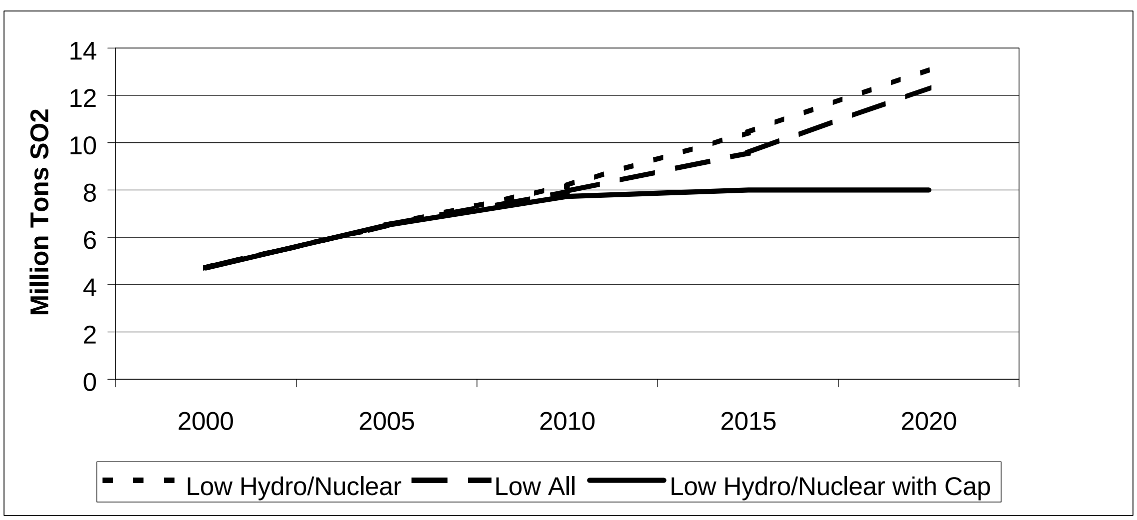


Figure 6.13
Variation of Power Sector SO_2 Emissions Under Advanced Technology Scenario



Comparative Costs

Total cumulative capital, operational and fuel costs over the period 2001-2020 for the five scenarios are presented in Table 6.9. Separate breakdowns for each type of cost are presented in Tables 6.10 and 6.11. Capital costs for the period 1996-2000 are shown in Table 6.10, but this period is not part of the cumulative costs in the table below.

Table 6.9
Total Cumulative Costs, 2001-2020

Scenario		Cost ($ Billion)
Baseline		1,070
Sulfur Control	Low Standard	1,335
	High Standard	1,585
	Low Fee	1,170
	High Fee	1,245
Carbon Dioxide Control	Low	1,180
	High	1,235
Natural Gas Policy	Baseline	1,355
	Low Capital	1,155
	Low Gas	1,160
Advanced Technology	Low Hyd/Nuc	1,225
	Low All	1,290
	Low Hyd/Nuc + Cap	1,400

The baseline scenario will cost a little over one trillion dollars for the twenty year period and is naturally less expensive than the other cases because it does not account for the true costs of electricity production. Environmental and health damages due to sulfur, fine particulates, carbon dioxide and other emissions, at a minimum, should be included in this scenario to make rational economic comparisons about future power needs.

For this reason, we believe the high fee sulfur control case is a better estimate of the actual costs to meet China's future power needs. This case has internalized the damage done by sulfur dioxide emissions through use of an SO_2 emission fee system. Damages from other pollutants and processes should also be included, but this went beyond the scope of our study. Cumulative costs in this case are 16 percent higher than the baseline scenario, while the power generation mix required to minimize total costs is significantly different. (See Figure 6.2.) By including other environmental externalities, these total costs could easily exceed 1.5 trillion dollars, making all but the high sulfur standard case justifiable to follow.

The low capital natural gas case is only about 8 percent more expensive than the baseline scenario and at least 8 percent cheaper than the high sulfur fee case. At the other extreme, the high standard sulfur control case is almost 50 percent more expensive than the baseline (but roughly equal to the true absolute cost of electricity production).

Table 6.10
Comparative Capital Investment Costs for the Five Scenarios ($ Billion)

	Case	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020
Baseline		82	120	106	88	96
Sulfur Control	Low Standard	120	151	124	108	124
	High Standard	120	153	131	116	152
	Low Fee	116	154	128	103	111
	High Fee	117	162	133	112	116
Carbon Dioxide Control	Low	116	153	125	114	123
	High	138	154	123	151	176
Natural Gas Policy	Baseline	116	153	125	99	107
	Low Capital	116	153	125	99	98
	Low Gas	116	153	112	78	83
Advanced Technology	Low Hyd/Nuc	109	144	117	93	100
	Low All	101	148	116	91	106
	Low Hyd/ Nuc + Cap	101	148	130	123	158

Table 6.11
Comparative Operational and Fuel Costs for the Five Scenarios ($ Billion)

		Operational Costs			Fuel Costs		
	Case	**2000**	**2010**	**2020**	**2000**	**2010**	**2020**
Baseline		4	8	12	10	20	42
Sulfur Control	Low Standard	4	8	15	12	27	55
	High Standard	10	18	40	11	24	51
	Low Fee	4	9	14	12	20	41
	High Fee	4	10	16	11	22	43
Carbon Dioxide Control	Low	5	8	13	12	20	39
	High	5	9	16	10	20	32
Natural Gas Policy	Baseline	5	8	13	16	30	55
	Low Capital	5	8	13	11	21	42
	Low Gas	4	9	14	10	21	50
Advanced Technology	Low Hyd/Nuc	5	10	17	15	24	42
	Low All	5	10	15	16	26	51
	Low Hyd/Nuc + Cap	5	10	19	18	27	45

7. Conclusions & Policy Recommendations

Environmental pollution in China is expensive. The World Bank estimates that air and water pollution cost China's economy about 8 percent of GNP each year. Millions of premature deaths and illnesses could be avoided each year if China met its class 2 air quality pollution standards. Sulfur dioxide emissions, which come increasingly from power plants, cause extensive damage over large regions of China. Each ton of these emissions, in combination with significantly lesser emissions of nitrogen oxides, causes approximately $515 of damage to human health, agriculture and other systems in China. Particulate emissions from the power sector have been stabilized now that new plants must use electrostatic precipitators, but old plants are still responsible for harmful emissions.

Affordable technologies are available to help China reduce the overall cost of pollution damage. It is cheaper to install desulfurization equipment on new power plants in the south and east than to bear the health and environmental damage due to sulfur dioxide emissions. Initiating policies to make more natural gas available at competitive prices will further reduce environmental damage due to sulfur, nitrogen, carbon, and particulate emissions. Advanced technologies such as integrated gasification combined cycle and fuel cells could be developed faster in China to further reduce environmental damages. The costs of wind energy continue to decline and if China finds a way to increase the availability of this power source, perhaps through compressed air energy storage or flywheels, it can contribute to an electricity supply system with fewer environmental impacts. Characteristics of the main power supply technologies are summarized in Tables 7.1 and 7.2.

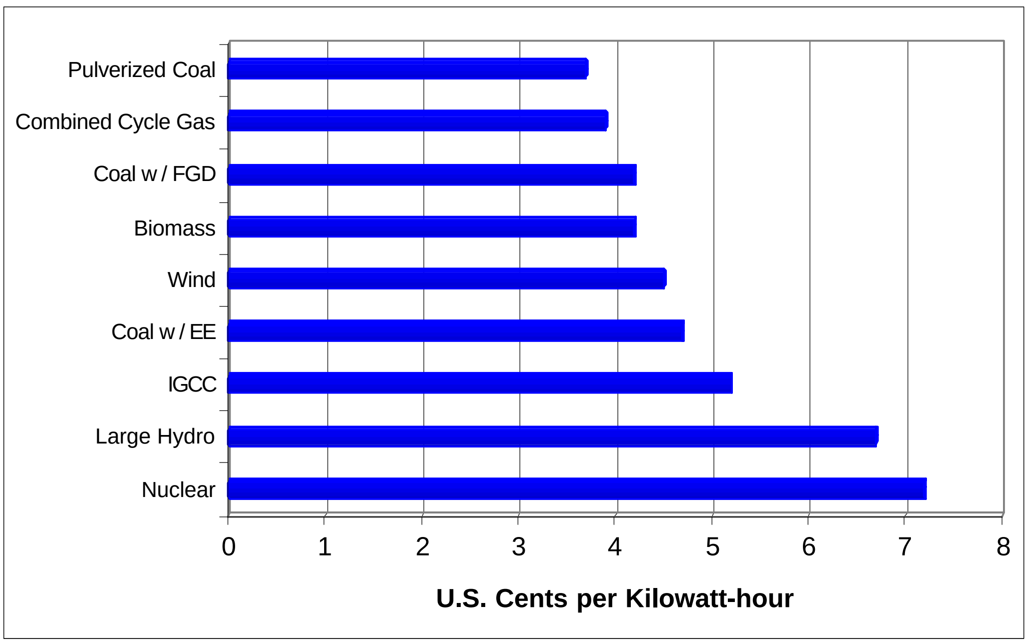
Table 7.1
Electric Power Options

Fuel	Technical Costs	Environmental Costs	Fuel Costs	Overall Costs
Pulverized Coal	Low	Very High	Low	High
Clean Coal	High	Moderate	Low	High
Nuclear	Very High	Unknown	Low	High
Hydro	Very High	Mixed	None	High
Gas	Low	Low	Moderate	Moderate
Wind	Moderate	Low	None	Moderate

Pulverized coal power generation costs are lower than most other technologies, except in regions where natural gas is cheap. (See Figure 7.1.) Coal combustion is environmentally damaging, however. Internalizing the damage done due to sulfur emissions raises the true cost of coal-based power generation by 30 percent in southern, coastal China. Installing flue gas desulfurization equipment is a cheaper alternative. Clean coal technologies such as IGCC and PFBC will be promising alternatives if capital costs can be reduced, although carbon emissions will still remain relatively high.

Gasified biomass power generation is also promising but the technology still needs to be developed and biomass fuels may have higher priority alternative uses. Wind power can be generated competitively, but low capacity factors limit the usefulness of this renewable source. Increasing the availability of wind and making it a base-load power option will depend on the development of energy storage systems using compressed air, pumped water, or flywheels. Analysis of the development of these energy storage mechanisms went beyond the scope of this study and should be further considered for future use in China. Photovoltaic power will not make a big impact on China's aggregate electricity mix by 2020 unless capital costs drop to below $1,500 per kilowatt, about one-third of today's level.

Figure 7.1
Power Generation Costs in Southeastern China, 1998



Note: Coal w/ EE means pulverized coal power generation with sulfur costs internalized. Does not include transmission costs. See Summary Table 1 and Table 5.11 for other assumptions.

Large hydropower plants are expensive and may only be competitive on a case by case basis when the associated flood control and transportation benefits are included. Environmental impacts are often lowered in small hydro stations. Nuclear power is not economically competitive, even assuming the technology can be completely manufactured domestically.

Table 7.2
Fuel Issues in the Chinese Power Sector

Fuel	Issues
Pulverized Coal	Supply-Demand Imbalance, Polluting
Gas	Distorted Market, Undeveloped Infrastructure
Nuclear	High Capital Costs
Clean Coal (IGCC, FBC)	Relatively Expensive and Unproven
Biomass	Immature Technology, Other Fuel Priorities
Wind	Low Capacity Factor
Large Hydro	Expensive, Environmental Impacts

Recommendations

Sulfur Control: It is cheaper to install sulfur control equipment on new plants in the south and east than to incur the environmental and health damage of uncontrolled emissions. China would benefit from speeding up development of flue gas desulfurization technology and enforcing sulfur emission regulations. Reducing SO_2 emissions from coal-fired power plants is easier and cheaper than from other coal-burning equipment such as boilers and furnaces. A higher percentage of coal will be burned to generate electricity in the future while the share burned by low efficiency boilers and furnaces will drop. Therefore, expanding the use of washed coal and speeding up the commercialization of FGD technologies should be given greater emphasis. Initiating a sulfur permit or stricter tax system may be the cheapest way to cut growth in future emissions.

Combined cycle gas turbines: This is now the cheapest and cleanest form of power generation in many countries. China could lower the capital and operational costs of CCGT technology by initiating an accelerated R&D program and demonstrating world-class turbines, possibly through joint-ventures with leading manufacturers in other countries. If China boosts development of natural gas supplies and begins to domestically manufacture combined cycle gas turbines, power generation from gas-fired combined cycle systems will become a viable and attractive option in southern coastal regions. This is also the cheapest way to control CO_2 emissions in the power sector.

Natural Gas: Despite a weak history in China, natural gas can play a larger role in fueling a clean, efficient economy. Barriers currently limiting the availability of natural gas in China can be addressed if the government takes a fresh look at its potential. China should remove distortions in the natural gas market. These distortions arise from setting gas prices far below market value, allocating gas use to specific industries, and ignoring the environmental benefits of gas over coal. Average gas prices are fixed below market value in many regions, stifling incentive to explore for new supplies. The government allocates a significant fraction of China's natural gas to the industrial and the fertilizer sectors, resulting in inefficient use. Natural gas would have a higher value in the market if its environmental benefits over coal were included in economic decision-making.

LNG Development: Average liquefied natural gas prices in Asia have been declining for the past 10 years. In Japan, prices for imported LNG have dropped 30 percent from over $5 per GJ in 1985 to about $3.75 per GJ in 1995.[105] China could probably construct similar LNG terminals along its coast but at lower overall costs than in Japan. The financial crisis in Asia has recently made more LNG available on the world market. South Korea, Thailand, and Japan are reducing by up to 25 percent their planned imports of LNG through 2007, making more available for other Asian countries. China could capitalize on this valuable source of energy while prices remain low. In southeastern China, the government should study the construction of LNG import terminals wherever a delivered price of $3.50 per GJ or less is available. This is the price where combined cycle natural gas power is usually cheaper than coal-fired power with scrubbers. Barriers to importing LNG include financing for terminal construction and pipeline infrastructure, and lack of a strong supporter within the government. LNG imported solely for power generation, however, would not need an extensive pipeline infrastructure.

Hydropower development: China's huge hydropower resources are considered a viable option for improving the country's energy supply structure, and reducing SO_2 and CO_2 emissions. Hydropower costs used in this study make it appear uneconomic compared to other technologies, but capital costs for hydropower plants are often high because other non-power related functions (such as flood control and improved navigation) are also served. Hydropower planning thus needs careful attention and support from the government. We suggest that a more comprehensive analysis be performed in the future to evaluate the full economic costs and benefits of hydropower development. Small plants often have fewer environmental and social impacts than larger ones.

Nuclear power: Nuclear power is less competitive than coal-fired power, even in the cases where SO_2 emission control and environmental externalities are considered. Nuclear power provided approximately 10 percent of the least-cost power mix in the scenarios where CO_2 emissions were cut by 30 percent from the baseline and when capital costs were assumed to decline by one-third from today's level.

Renewable Power Generation: Wind, photovoltaic and biomass power generation can contribute to China's electricity future, but costs must first decline and other barriers must be addressed. At present they are not competitive for base-load power compared to conventional electric power generation technologies due to high capital costs and limited capacity as a reliable electric power source. The low capacity factor of most wind farms, for example, explains why this power source cannot compete against other technologies, despite relatively low capital costs. We did not model the energy storage systems that could potentially raise capacity factors high enough to make wind a base-load option capable of competing with coal-fired power plants in certain regions by 2010, but recommend that future research address this opportunity. Capital costs for photovoltaic electric cells are declining rapidly, but this technology will not have a significant impact on the country's generation mix until costs drop to $1,500 per kilowatt or lower. Gasification technologies developed for coal can be adapted to biomass. This process could be especially valuable if China decides to isolate and sequester carbon dioxide. At a minimum, renewable energy sources can play a supplementary role in remote areas where electric power grids can not be extended, or in places where exploitation conditions are highly favorable.

Clean coal technologies: Capital investment costs for clean coal technologies are currently high compared to China's conventional coal-fired power systems with FGD. The technology also remains largely unproven in China. In regions where coal prices are also high, IGCC and PFBC are less competitive than natural gas-fired combined cycle gas turbines. Because coal will remain available far into the future, China may want to maintain efforts to develop advanced clean coal technologies. Coal gasification could be an important long-term technology to develop in China. China will not make a large-scale effort to deploy this technology, however, unless capital costs decline significantly.

Efficiency remains China's least-cost option: China's cheapest option is to continue its successful efforts to conserve energy and raise energy efficiency. Raising energy efficiency is often cheaper in China than adding new supply.[106]

China has made impressive progress: China has achieved unprecedented success in energy conservation since the late 1970s. The government has held energy elasticity at or below 0.5, meaning that the economy is growing twice as quickly as energy consumption. Without this action to cut energy use, China would now be consuming about twice as much energy as it actually does and emitting twice as much carbon into the atmosphere.

Use of foreign direct investment: The Chinese government wants foreign private investment in the power industry to fill the shortage of financing and introduce advanced technologies. Barriers related to transparency, risk, and return on investment, however, often inhibit greater use of foreign private capital. Foreign investors may attempt to bypass these barriers by developing small, inefficient power plants, further exasperating environmental problems. Build, own, transfer (BOT) projects have received new attention as a way to overcome some of the difficulties, but the private market is unlikely to play a more substantial role in China's power sector until additional reforms and incentives are implemented.

Rational allocation of power generation: Long-distance transmission of electricity is a cost-effective method of meeting demand in some regions. Transmission may be economic from the southwest to Guangdong and from the north and northwest regions to the east and central regions. Transmitting electric power from these regions is cheaper and more environmentally attractive, generally, than transporting coal. Development of electric power generation in the north and northwest, however, may be limited by the availability of water supply in these regions.

Improving overall energy supply mix: China's electric power supply is dominated by coal-fired capacity and this trend is likely to continue into the foreseeable future. Some researchers have focused on ways for China to improve the structure of its power generation, including substituting natural gas for coal. While this practice has either happened or is happening in many developed countries, China has some additional problems to overcome before it can do the same. At present, coal is the dominant fuel used in China not only in the power sector, but also in industrial and housing sectors. The total consumption at present is 1.4 billion tons, and less than 40 percent of this coal is used for power generation. The remaining one billion tons are used in metallurgy, chemicals, and hundreds of thousands of small industrial boilers, furnaces, and stoves. Compared with the electric power industry, coal utilization in these sectors is much less efficient and results in more severe environmental problems. Pollution control is more expensive than in the electric power industry. Hence, it is more rational to first use more natural gas and other clean energy sources to substitute for coal in these sectors. This will improve energy efficiency and reduce emissions, and is hence an important priority for China.

Interregional authority: Current restructuring in the government is resulting in decentralization and greater decision-making authority at the provincial and local levels. It is important for a national or interregional body to maintain responsibility for nation-wide power planning so that unified and coordinated decisions can be made. Only a supra-provincial agency, for example, would be able to coordinate the decision to send power rather than coal from southwest China to Guangdong.

All modeling has limitations, and this effort is no exception: Linear programming does not reproduce observable behavior found in market economies. Higher energy prices, for example, do not lead to reduced demand in linear programming models. Real-life investment decisions, furthermore, are difficult to simplify in the way that linear programming models require (they do not, for example, value risk and convenience, or account for habit). Further studies of this type could take advantage of the strengths found in linear optimization models while incorporating the benefits of models such as general equilibrium models based more on observable behavior.

8. Endnotes

1. "China: Acid Rain Damage Costs Country More Than $13.25 Billion," *Xinhua News Agency*, (Beijing: 3 March 1998). Based on the total damage mentioned in the article above, China's 23.7 million tons of emissions cost the economy roughly $515 per ton on average, although nitrogen oxides are responsible for at least some of this damage. In this study, we use sulfur dioxide externality estimates ranging from $157 to $965 per ton of SO_2.

2. World Bank, *China 2020: China's Environment in the New Century: Clear Water, Blue Skies* (Washington, D.C.: World Bank, 1997). Class 2 air quality standards are for residential urban and urban areas, and are comparable to those of the World Health Organization. According to this report, over 178,000 premature deaths and millions of illnesses could be avoided each year if China met its class 2 air quality pollution standards. Another World Bank report states that smoke and fine particulates cause 50,000 premature deaths and 400,000 new cases of chronic bronchitis in 11 large Chinese cities each year. The cost of air pollutin in these 11 large cities is calculated to be greater than 20 percent of urban income. See World Bank, *Can the Environment Wait? Priorities for East Asia*, (Washington, DC: World Bank, 1997).

3. This study recognizes previous work in the field by the Nautilus Institute, also funded by the W. Alton Jones Foundation. For a list of publications by the Nautilus Institute, see their home page at URL: http://www.nautilus.org/index.html.

4. See, for example, Beijing Energy Efficiency Center, "Integrated Resources Planning Feasibility Study in Shenzhen: Summary Report" (unpublished) (Washington, D.C.: Pacific Northwest National Laboratory, 1994) for a discussion of demand side versus supply side costs.

4. In the baseline scenario, Pacific Northwest National Laboratory estimates average capital investment costs for coal-fired power plants of $663 per kilowatt. This estimate differs from the ERI estimate of $603 per kilowatt because of differences in efficiency measurements, the way future costs are expected to rise, and the average size of new capacity additions.

5. Supercritical units use steam with a working pressure of 237 atmospheres (24 megapascals) and higher.

7. In late 1997 and early 1998, the big three U.S. car manufacturers announced plans to develop production-ready fuel cell cars by 2004. Daimler-Benz, Toyota, and Mazda have even more ambitious plans. Solid oxide cells for stationary power and heat will probably reach the market even sooner.

8. For a discussion of compressed air energy storage, see Debra Lew, Robert Williams, Xie Shaoxiong, and Zhang Shihui, "Industrial-Scale Wind Power in China." Available URL: http://crest.org/renewables/wind/index.html.

9. An exajoule equals 0.95 quadrillion BTU. See the appendix for a table of energy conversion factors.

10. U.S. Department of Energy, (Washington, DC: Energy Information Administration, 1998). Available URL: http://www.eia.doe.gov/emeu/international.

11. Ibid.

12. For a discussion of China's accomplishments in energy efficiency, see Jonathan Sinton, Mark Levine, and Wang Qingyi "Energy Efficiency in China: Accomplishments and Challenges." (Draft Report, Berkeley, CA: May 1996).

13. State Economic and Trade Commission, *China Energy Annual Review 1996* (Beijing: SETC, 1996); "China to Attain 8% Economic Growth Rate," *China Business Net*, (Beijing: 6 March 1998).

14. In 1995, China's net fuel consumption rate for coal-fired power plants was 412 gce/kWh (29.8 percent efficient), over 25 percent higher than the international average. *China Energy Development Report* (Beijing: Economic Management Publishing House, 1997) and *China Energy Annual Review 1996.*

15. *China Energy Annual Review, 1996.*

16. "China's Electricity output up 6.8% last year," *China Business Net*, (Beijing: 5 March 1997).

17. *"*China '97 Electricity Output a Record 1.14 Trillion kWh," *Reuters*, 2 February 1998.

18. *China Energy Annual Review, 1996.*

19. Preliminary energy statistics for 1997 as reported in "China's Power Output Up 5.2 Percent in 1997," *China Daily*, (Beijing: 29 December 1997).

20. *China Energy Annual Review, 1996.*

21. *"*China's Electricity Output up 6.8% Last Year," *China Business* Net, (Beijing: 5 March 1997).

22. "China '97 Electricity Output a Record 1.14 Trillion kWh" *Reuters*, 2 February 1998.

23. For a description of why these combined cycle units were constructed, see Allen Blackman and Xun WU "Climate Impacts of Foreign Direct Investment in the Chinese Power Sector: Barriers and Opportunities," Draft, (Washington, D.C: Resources for the Future, 1997).

24. Ibid.

25. U.S. Department of Energy, *International Energy Outlook 1997,* (Washington, DC: Energy Information Administration, 1997).

26. *China Energy Statistical Yearbook 1991* (Zhongguo Nengyuan Tongji Nianjian 1991), (Beijing: State Statistical Bureau, 1992).

27. *China Electric Power Industry Statistical Yearbook 1995* (Zhongguo Dianli Gongye Tongji Nianjian), (Beijing: State Statistical Bureau, 1996).

28. Jonathan Sinton, Mark Levine and Wang Qingyi.

29. *China Energy Statistical Yearbook 1991.*

30. *China Electric Power Industry Statistical Yearbook 1995*.

31. *China Energy Statistical Yearbook 1991.*

32. *China Electric Power Industry Statistical Yearbook 1995*.

33. *China Prices 1995-96* (Zhongguo Jiage), (Beijing: State Statistical Bureau, 1996-97).

34. *China Electric Power Industry Statistical Yearbook 1995*.

35. See Jeffrey Logan "Energy Consumption and Economic Change in China: An Econometric Study," East-West Center Working Papers (Honolulu: East-West Center, 1995) or Binsheng Li and James Dorian "China's Power Sector Undergoing Dramatic Change," *Energy Policy* 23(8) 1995.

36. "Policy Research on Sino-Foreign Jointly-Funded Power Projects," (Zhongwai Gongtong Touzi Dianli Xiangmu Zhengce Yanjiu), (Beijing: Energy Research Institute, 1995).

37. A dozen of China's forty one ministries were disbanded at this Congress. One of the biggest restructuring acts was in the State Economic and Trade Commission, which absorbed several of the disbanded organizations and became a "super ministry". It is too early to predict the impact of restructuring some organizations such as the former Ministry of Electric Power Industry.

38. *China 2020: Clear Water, Blue Skies.* Vaclav Smil argues in "Environmental Problems in China: Estimates of Economic Costs," (Honolulu, HI: East-West Center, April 1996) that this figure should be at least 10 percent of GDP.

39. Vaclav Smil, *China's Environmental Crisis: An Enquiry into the Limits of National Development* (Armonk, NY: M.E. Sharpe, 1993).

40. The *China Business Net* reported on January 12, 1998 that of these 65,000 tanneries, paper mills and coking plants, more than 1,000 had resumed production after closure, and more than 93 percent of those were closed down again.

41. For a more complete discussion of this phenomenon, see Kenneth Lieberthal, "China's Governing System and its Impact on Environmental Policy Implementation," (Washington, D.C.: Woodrow Wilson Center, *China Environment Series*, 1997).

42. More information on China's Agenda 21 can be found on the China Dimensions section of the Consortium For International Earth Science Information Network's (CIESIN) home page. Available URL: http://www.ciesin.org.

43. Wang Zhixun, "Current Situation of Air Pollution in the Electric Power Industry and Prevention Strategy," (Dianli Gongye Kongqi Wuran Zianzhuang he Fangzhi Zhanlue) published in "International Conference on Environmental Protection of Electric Power Industry," (Nanjing: Ministry of Electric Power Industry, 1996).

44. Ibid.

45. See, for example Joint Study Team from the National Environmental Protection Agency of China, *China: Issues and Options in Greenhouse Gas Control*, (Washington, DC: World Bank, 1994), or East-West Center, Argonne National Laboratory, and Tsinghua University, *National Response Strategy Global Climate Change: People's Republic of China*, (Manila, Philippines: Asian Development Bank, 1994).

46. Anne Gruettner, "Regulations Irk Suppliers, *South China Morning Post*, *China Business Review*, October 30, 1997.

47. *China Statistical Yearbook 1996*.

48. Ibid.

49. Ibid.

50. *Compiled Summary of China Electric Power Industry Statistics* (Zhongguo Dianli Gongye Tongji Zhaiyao), (Beijing: Ministry of Electric Power Industry, 1996).

51. Ibid.

52. For more information on MEDEE (Modèle d'Evaluation de la Demande En Energie), see B. Lapillone and B. Chateau, *The MEDEE Models for Long-Term Energy Demand Forecasting*, Proceeding of the International Conference on Energy Systems Analysis, Dublin/Ireland, Oct. 9-11, 1979; or Government of China/UNDP/ESCAP, *Sectoral Energy Demand Studies in China*, Bangkok, ESCAP, November 1989.

53. "Analysis of Medium-Long Term Electric Power Demand and Supply," (Zhong-Changqi Dianli Gongxu Fenxi), (Beijing: Energy Research Institute, 1996).

54. "Analysis of Medium-Long Term Electric Power Demand and Supply"; "Long-Term Energy Demand Forecast," (Changqi Nengyuan Xuqiu Yuci), (Beijing: Qinghua University, 1994); "Research on Energy Development Strategy," (Nengyuan Fazhan Zhanlue Yanjiu), (Beijing: Electric Power Research Academy, 1994).

55. *China Statistical Yearbook 1996*.

56. *Coal Industry Statistics* (Meitan Gongye Tongji), (Beijing: Ministry of Coal, 1996).

57. Jonathan Sinton, ed. *China Energy Databook* (Berkeley, California: Lawrence Berkeley Laboratory, 1996 update).

58. *China Annual Energy Evaluation* (Zhongguo Niandu Nengyuan Pingjia), (Beijing, 1996).

59. "International Petroleum Economy" (Guoji Shiyou Jingji), (Beijing: Petroleum Planning Academy, 1997).

60. British Petroleum's *Statistical Review of World Energy 1997*, CEDIGAZ's *Natural Gas in the World 1996 Survey*, C.D. Master's and others "World Resources of Crude Oil and Natural Gas: Proceedings of 13th World Petroleum Congress" (1992) and the International Energy Association 1996.

61. Approximately 2,000 coal miners lose their lives each year in major accidents in China's coal mines. Accidents in the country's numerous small, unregulated mines account for an additional 8,000 deaths. "China Coal Mine Blast Kills 77, Injures Eight," *Reuters*, 30 January 1998.

62. "Companies Cooperate to Develop Methane Resources," *China Business Net*, 9 January 1998.

63. "Current Status and Prospective for Natural Gas Pipeline Transport in China" (Zhongguo Tianranqi Guandao Shusong Xianzhuang he Qianjing), (Beijing: Petroleum Planning Academy, 1997).

64. Ibid.

65. "Output of China's Major Energy Resources Rises in 1996," *Xinhua*, 1 February 1997.

66. Oil imports are projected to surpass one million barrels per day by 2000 and three million by 2010. See David Fridley, "China: Energy Outlook and Investment Strategy," Presented at *Oil and Money Conference*, London, UK 18-19 November 1997.

67. *China Energy Databook*.

68. "Research on Energy Alternatives in the Future," (Weilai Nengyuan Xuanze Yanjiu), (Beijing: Energy Research Institute, 1996).

69. E. Stratos Tavoulareas and Jean-Pierre Charpentier, *Clean Coal Technologies for Developing Countries*, (Washington, D.C.: World Bank, 1995).

70. Modified from Tavoulareas and Charpentier for China's conditions.

71. For more background information on these technologies, see Tavoulareas (1995) or Electric Power Research Institute, 1993, *Proceedings of the SO_2 Control Symposium* (Section 5A). Boston, Massachusetts, August 24-27, Palo Alto, California, United States.

72. Gruettner, Anne, "Regulations Irk Suppliers," *China Business Review*, 30 October 1997. Available URL: http://www.scmp.com/news/special/cbrenergy/topcbr.idc.

73. One of the first large supercritical units to operate in China was in Shanghai (Shidongkou II). Brought on-line in 1995, this plant had a design efficiency of 39 percent (317 gce/kWh). So far, only the World Bank has been willing to finance these high-efficiency, supercritical plants. See Blackman and Wu (1997) for more background.

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Appendices

A. Mathematical Description of the Linear Optimization Model

B. Overview of Levelized Cost Analysis

C. Abbreviations

D. Bibliography

E. Conversions

A. Mathematical Description of the Model

The model employed in this study is a least-cost optimization model. The objective function of the model is defined to minimize the entire system cost including power generation costs, coal cleaning and transportation costs, electricity transmission costs, pollution control costs, and the external damage costs of pollution emissions whenever they are applied. In mathematical terms, then, the goal is to minimize:

$$\min Z = \sum_{t}^{T} \delta_t \Bigg[\sum_{j \in J} (inv_{t,r,j} XC_{t,r,j} + opr_{t,r,j} XE_{t,r,j}) + \sum_{r \in R} \sum_{f \in F} (pro_{t,r,f} XPF_{t,r,f} + imp_{t,r,f} IP_{t,r,f})$$

$$+ \sum_{r \in R} \sum_{r1 \neq r} (\sum_{f \in F} trp_{t,r1,r,f} TR_{t,r1,r,f} + inv_{t,r1,r} TC_{t,r1,r} + trm_{t,r1,r} TE_{t,r1,r})$$

$$+ \sum_{r \in R} \sum_{p \in P} dmg_{t,r,p} \sum_{j \in JTh} \sum_{f \in F} \varepsilon_{j,f,p} XF_{t,r,j,f} \Bigg]$$

where,

$XC_{t,r,j}$ ____ generating capacity variable;

$XE_{t,r,j}$ ____ electricity generation variable;

$XPF_{t,r,j}$ ____ fuel production variable;

$IP_{t,r,j}$ ____ fuel import variable;

$TR_{t,r1,r,f}$ ____ fuel transportation variable;

$TC_{t,r1,r}$ ____ electricity transmission capacity variable;

$TE_{t,r1,r}$ ____ electricity transmission variable;

$XF_{t,r,j,f}$ ____ fuel consumption variable;

and,

δ_t is a discount factor; $\varepsilon_{j,f,p}$ is an emissions factor; $inv_{t,r,j}$, $opr_{t,r,j}$, $pro_{t,r,j}$, $imp_{t,r,j}$, $trp_{t,r1,r,f}$, $inv_{t,r1,r}$, $trm_{t,r1,r}$, $dmg_{t,r,p}$ are cost factors; and T, R, J, JTh, F, P represent sets of time periods, regions, generating technologies, fossil-fired generating technologies, fuels and pollutants.

The major constrains of the model are as follows:

1. Capacity constrains

$$\sum_{j \in J} XC_{t,r,j} + \sum_{r1 \neq r} TC_{t,r1,r} - \sum_{r1 \neq r} TC_{t,r,r1} \geq \underline{DC}_{t,r}$$

$$XC_{t,r,j} \leq \overline{XC}_{t,r,j}$$

$$TC_{t,r1,r} \leq \overline{TC}_{t,r1,r}$$

$$TC_{t,r,r1} \leq \overline{TC}_{t,r,r1}$$

where $\underline{DC}_{t,r}$ is largest load capacity of a given region; and $\overline{XC}_{t,r,j}$, $\overline{TC}_{t,r1,r}$, $\overline{TC}_{t,r,r1}$ are maximum available capacities including newly built capacities.

2. Electricity balance constrains

$$\sum_{j \in J} XE_{t,r,j} + \sum_{r1 \neq r} TE_{t,r1,r} - \sum_{r1 \neq r} TE_{t,r,r1} \geq \underline{DE}_{t,r}$$

$$XE_{t,r,j} \leq \sum_{f \in F} \eta_{r,j,f} XF_{t,r,j,f}, \quad j \in JTh$$

$$XE_{t,r,j} \leq \overline{XE}_{t,r,j}, \quad j \notin JTh$$

where $\underline{DE}_{t,r}$ is electricity demand of a given region; $\overline{XE}_{t,r,j}$ is maximum annual electricity generation of a given technology, and $\eta_{r,j,f}$ is generation efficiency.

3. Fuel balance constrains

$$\sum_{j \in JTh} XF_{t,r,j,f} \leq XFP_{t,r,f} + \sum_{r1 \neq r} TR_{t,r1,r,f} - \sum_{r1 \neq r} TR_{t,r,r1,f} + IP_{t,r,f}$$

$$XFP_{t,r,f} \leq \overline{XFP}_{t,r,f}$$

$$TR_{t,r1,r,f} \leq \overline{TR}_{t,r1,r,f}, \quad r1 \neq r$$

$$TR_{t,r,r1,f} \leq \overline{TR}_{t,r,r1,f}, \quad r1 \neq r$$

where $\overline{XFP}_{t,r,f}$, $\overline{TR}_{t,r1,r,f}$, $\overline{TR}_{t,r,r1,f}$ are maximum available fuel production and transportation capabilities.

4. Emission constrains

$$\sum_{j \in JTh} \sum_{f} \varepsilon_{j,f,p} XF_{t,r,j,f} \leq \overline{PE}_{t,r,p}$$

where $\overline{PE}_{t,r,p}$ is the maximum permissible emissions of a given region.

B. Overview of Levelized Cost Analysis

Levelized cost analysis is used in the power sector to compare the cost of generating electricity from different sources with different financial lifetimes. The methodology spreads out all costs involved in building a facility and producing electricity over the economic life of the plant so the final kilowatt-hour costs can be directly compared.

The total cost per unit of electricity is

$C/kWh = (K_a + FC + O\&M + EX + SF)/kWh$

where
C = total cost
kWh = kilowatt hour
K_a = capital cost on an annualized basis, including construction
FC = fuel cost
O&M = annual operations and maintenance costs
EX = annual environmental externalities (costs to humans, agriculture, ecosystems, and materials)
SF = sinking fund on an annual basis, to address long term nuclear decomissioning and/or clean up costs.

Step 1: Find Annual Capital Cost per Unit
$K_a = K_{kW} * ACCR$

where
K_a = annual capital cost per unit (usually expressed as $/KW/year)
K_{kW} = total capital costs per kW
ACCR = annual capital charge rate = $I/(1-(1+I)^{-n})$
I = the interest or discount rate
n = the number of years assumed for the financial lifetime of the facility.

Capital costs begin to accumulate during the preoperational phase and should be accounted for as follows: total capital construction costs, $K = Sum_{i=1,t} (f_i (1+I)^i)$, where f_i are the funds expended in construction year i before plant operation and t is the total number of years of construction before plant operation. Dividing by kW gives K_{kW}.

Step 2: Find Fuel Costs per Unit
FC/kWh = HR * FP

where:
FC = fuel costs
HR = heat rate = fuel/kWh (often assumed) = MJ/kWh
FP = fuel cost per unit (often assumed) = $/GJ.

A fuel cost escalation term may also be used here. For example, if fuel costs are expected to rise by FE x 100% per year, then:

FP_{av} = average fuel price during N years of operation = \$/physical unit
FP_{av} = sum $_{i=0, n-1}$ $(FP_0 (1+FE)^i)/N$
where
FP_0 = fuel price in the initial year.

Step 3: Find O&M Costs per Unit

O&M/kWh = $O\&M_a$ / Thr/yr

where
O&M/kWh = operations & maintenance costs in cents/kWh
$O\&M_a$ = annual O&M costs, total, in dollars
Thr/yr = hours per year of operation of a kW.

Step 4: Annual Environmental Costs per Unit

EX/kWh = EX_a /Thr/yr

where
EX/kWh = environmental externality costs in dollars/kWh
EX_a = total annual environmental externality costs, in dollars per kW
Thr/yr = hours per year of operation of a kW.

Step 5: Sinking Fund Costs per Unit

SF/KWh = SF_a /Thr/yr

where
SFa = annual sinking fund level in dollars/kWh = $TC * (I'*(1+I')^{n'}/((1+I')^{n'} - 1))$

and
TC = total present value of decommissioning or cleanup costs.

Step 6: Add all costs

Total Levelized Cost = $K_a + FC + O\&M_a + Ex_a + SF$

C. Acronyms and Abbreviations

Term	Meaning	Term	Meaning
ARCR	acid rain control area	LHV	lower heating value
AFBC	atmospheric fluidized bed combustion	LNG	liquefied natural gas
BCM	billion cubic meters	MOEP	Ministry of Electric Power
BOT	build, own, transfer	MOF	Ministry of Finance
CO_2	carbon dioxide	Mt	million tons
CBM	coal bed methane	MW	megawatt
EIA	Energy Information Agency	MWh	megawatt-hour
EJ	exajoule	PFBC	pressurized fluidized bed combustion
ERI	Energy Research Institute (of the SPC)	PM	particulate matter
FDI	foreign direct investment	PNNL	Pacific Northwest National Laboratory
FGD	flue gas desulfurization	PV	photovoltaic
gce	gram of coal equivalent	RMB	Renminbi (Chinese Yuan)
GDP	gross domestic product	SO_2	sulfur dioxide
GHG	greenhouse gas	SECA	SO_2 emission control areas
GW	gigawatt	SOE	state-owned enterprise
HHV	higher heating value	SDPC	State Development Planning Commission
IEA	International Energy Agency	SETC	State Economic and Trade Commission
IGCC	integrated gasification combined cycle	tce	tons of coal equivalent
kgce	kilogram coal equivalent	TSP	total suspended particulates
kW	kilowatt	TVE	township and village enterprise
kWh	kilowatt-hour	TWh	terawatt hour

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CONVERSIONS

Energy

1 gigajoule = 1 x 10^9 joules
1 exajoule = 1 x 10^{18} joules

1 exajoule = 0.95 quadrillion British thermal units (Btu)
= 34.1 million tons of standard coal equivalent (Mtce)
= 47.8 million tons of Chinese average raw coal
= 23.9 million tons of Chinese average crude oil
= 26.5 billion cubic meters of standard natural gas
= 25.6 billion cubic meters of Chinese average natural gas
= 19.2 million tons liquid natural gas (LNG)
= 84.4 billion Kwh of electricity
= 59-71 million tons of air-dried firewood
= 62-83 million tons of air-dried crop residues

1 kilowatt (Kw) = 1 x 10^3 watts
1 megawatt (MW) = 1 x 10^6 watts
1 gigawatt (GW) = 1 x 10^9 watts
1 terawatt hour (TWh) = 1 x 10^{12} watt hour or 1 x 10^9 Kw

Currency

As of January 1, 1998

$1.00 = Y8.28
Y1.00 = $0.12