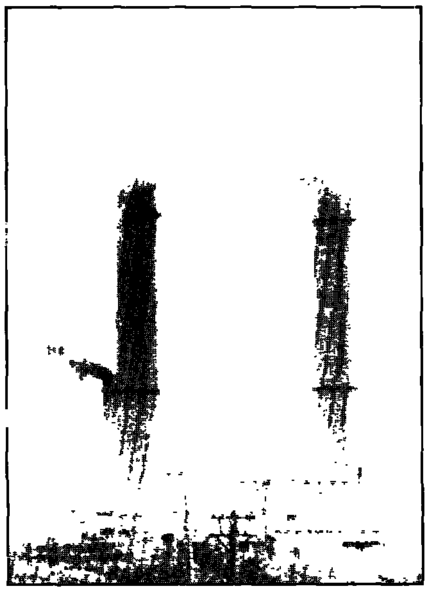
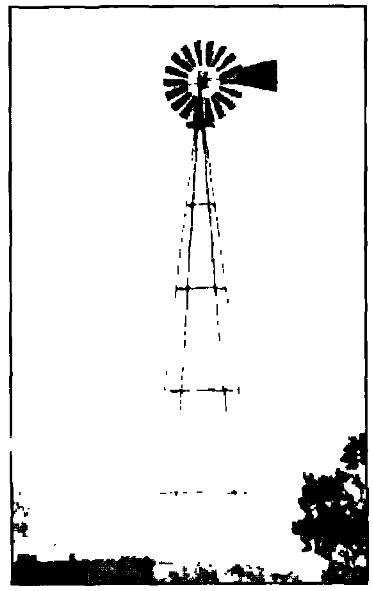
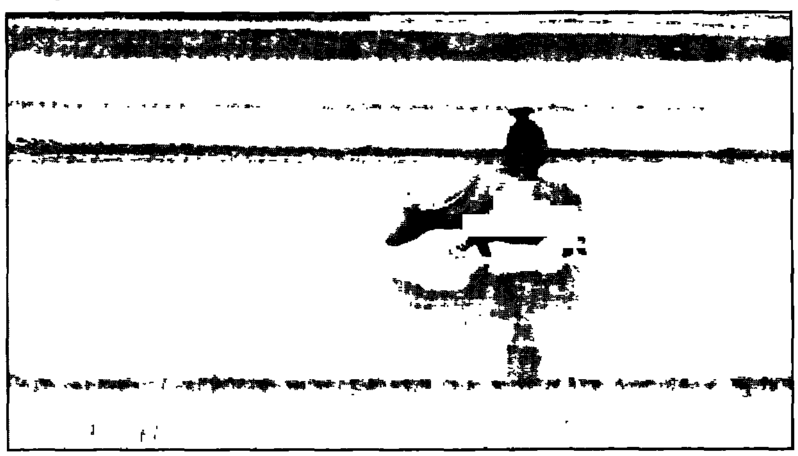
CHINA

Issues and Options in Greenhouse Gas Emissions Control







ALTERNATIVE ENERGY SUPPLY OPTIONS TO SUBSTITUTE FOR CARBON INTENSIVE FUELS

SUBREPORT NUMBER 5

Report of a Joint Team of Chinese and International Experts

December 1994

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Editors, Wu Changlun, Todd M. Johnson, Zhang Zhengmin, Robert M. Wirtshafter, Li Junfeng, and Li Jingjing

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Currency Equivalents

1 US$ = 4.7 Chinese Yuan (1990)

Weights and Measures

1 ton of coal = 0.7143 tce (average) = 20.934 GJ
1 ton of crude oil = 1.43 tce = 41.816 GJ
1,000 m^3 of natural gas = 1.33 tce = 38.931 GJ
1 ton fuelwood (air dry) = 0.54 tce
Kilo(Watt) = 10^3 (Watts), Mega = 10^6, Giga = 10^9, Tera = 10^{12}
All CO_2 weights expressed as molecular weight of carbon (C)

Abbreviations and Acronyms

bcm	- billion cubic meters
C	- carbon
CO_2	- carbon dioxide
EIRR	- economic internal rate of return
FIRR	- financial internal rate of return
GDP	- gross domestic product
GEF	- Global Environment Facility
GHG	- greenhouse gas
GJ	- gigajoule
GW	- gigawatt
kgce	- kilogram of coal equivalent
kW	- kilowatt
kWh	- kilowatt-hour
LNG	- liquified natural gas
LPG	- liquified petroleum gas
mcfd	- million cubic feet per day
MMbtu	- million British thermal units
mtce	- million tons of coal equivalent
MW	- megawatt
NO_X	- oxides of nitrogen
NPV	- net present value
PV	- photo-voltaic
SO_2	- sulfur dioxide
SPC	- State Planning Commission of China
t	- metric ton
tce	- ton of coal equivalent
TSP	- total suspended particulate
TW	- terawatt
TWh	- terawatt-hour

FOREWORD

This report is one of eleven subreports prepared as part of the United Nations Development Program (UNDP) technical assistance project, *China: Issues and Options in Greenhouse Gas Emissions Control,* funded by the Global Environment Facility, and executed by the Industry and Energy Division, China and Mongolia Department, of the World Bank. On the Chinese side, overall coordination for the project was handled by the National Environmental Protection Agency (NEPA), while the State Planning Commission (SPC) was responsible for work on energy efficiency and, alternative energy, the subject of this subreport.

This subreport is the product of a joint Chinese-international study team,** comprised of representatives from the SPC and the World Bank. The first international mission visited China in May of 1992 during which time the scope of the study and the methodology for calculating the cost of greenhouse gas (GHG) reduction were agreed upon. A number of background reports were commissioned at that time to be used as inputs to the study. Researchers on the international and Chinese sides prepared background reports on wind, solar, and nuclear technologies, and on natural gas development. A major effort was also undertaken by the SPC and the Energy Research Institute (ERI) to develop future scenarios of alternative energy supply in the years 2000, 2010, and 2050. This work was later modified and integrated with the macroeconomic and energy demand modeling effort undertaken as part of the overall China Greenhouse Gas Study. Given the different modeling frameworks, not all of the scenarios presented in this subreport are included in the final *Summary Report* for the overall China Greenhouse Gas Study. This final subreport makes extensive use of the background reports and alternative energy modeling work done by the Chinese side. This report was drafted and edited by Todd M. Johnson, Robert M. Wirtshafter, Wu Changlun, Zhang Zhengmin, Li Jingjing, and Li Junfeng.

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1. INTRODUCTION

1.1 This report is part of a larger study to assess the range of options in China for reducing greenhouse gas (GHG) emissions. Other study reports address the following mitigation issues: (i) reducing CO_2 emissions through improvements in energy efficiency, (ii) sequestering carbon in plants and soil through afforestation and forestry management practices, and (iii) reducing GHG emissions, primarily methane, in the agricultural sector, through changes in rice cultivation and animal husbandry practices. In the next 10-15 years, the most significant reductions in GHG emissions in China can be achieved by increasing the efficiency of energy use, particularly in the industrial, commercial, and residential sectors. In addition, because many of the energy efficiency projects that can be undertaken in China have fairly large financial and economic benefits,[1] they can provide GHG reduction at low cost. While there is significant potential for reducing GHG emissions through the adoption of low-carbon energy technologies, most are not yet commercially viable, and thus pose significant net costs in terms of GHG reduction. Nonetheless, over the long-term, the only option for stabilizing or reducing GHG emissions in China is by switching to non carbon-intensive energy sources.

1.2 The purpose of this report is to assess how much energy could be supplied by low carbon energy technologies in China over the coming decades, and how much an expanded alternative energy program would cost. Alternative energy supply scenarios have been prepared for China according to the following general principles: (i) from a technical standpoint, how much energy could be supplied by various technologies by a given date, and (ii) how much would it cost to supply various quantities of low carbon energy compared to the least-cost energy expansion plan. Because many alternative energy technologies are developing rapidly, there is a great deal of uncertainty in the estimates made in this report, which should be kept in mind when evaluating specific technologies and their costs. Nonetheless, it is clear that coal will continue to provide the majority of China's energy needs well into the 21st century. Therefore, this report focuses on the low carbon energy technologies that could be substituted for coal. Two broad types of technologies have been analyzed: (1) technologies that can substitute for coal for the generation of electric power and, (2) technologies that can substitute for coal for direct energy applications, such as industrial process heat, residential cooking, and space heating.[2] Both the CO_2 reduction potential and the costs of CO_2 reduction from alternative energy development have been analyzed.

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[1] Financial and economic analyses of energy efficiency projects have been undertaken as part of the China greenhouse gas study (see Subreport Number 4, *Energy Efficiency in China: Case Studies and Economic Analysis,* December 1994.) The majority of the projects reviewed in the case studies had positive net benefits when the financial and economic costs and benefits during the life of the project were considered. In addition, most all energy efficiency projects were found to have positive local environmental benefits in terms of reduced human health impacts from particulate and sulfur dioxide emissions.

[2] The direct use of energy in the transportation sector has not been addressed in this study due to the limited amount of coal that is used in the sector (for rail and ship) and the current lack of alternatives to petroleum products for internal combustion engines. In 199[illegible], the transport sector accounted for about 5 percent of commercial energy use in China.

A. Energy Use In China

1.3 China is presently the largest coal producing country in the world with production in 1990 at over 1 billion tons of raw coal. Coal currently accounts for more than three-quarters of total primary commercial energy consumption. Unlike developed countries, where coal is used mainly in power generation, in China the power sector accounts for only about a quarter of total coal consumption. Most coal in China is consumed by industry for steam generation and by the residential sector for cooking and heating. In 1990, non-power sector industrial boilers consumed more than 350 million tons of coal, accounting for about 35 percent of China's total coal use, while the residential sector consumed about 167 million tons of coal in 1990, or about 16 percent of total coal use.

Table 1.1 Primary Energy Consumption and Electricity Generation by Fuel, 1990

	Total Primary Commercial Energy Consumption (mtce)	%	Electricity Generation by Fuel Source (TWh)	%
Coal	752	76%	432	70%
Oil and Gas	184	19%	62	10%
Hydro	51	5%	127	20%
Nuclear	0	0%	0	0%
Other	0	0%	0	0%
Total	987	100%	621	100%

Source: China Statistical Yearbook (1990).

1.4 If present economic trends continue, energy use and GHG emissions in China could double or triple between 1990 and the year 2020.[3] This estimate is based on a "baseline scenario" that assumes continued economic growth (an average of 8 percent per year), continued improvements in energy efficiency, and, aside from imports of oil for the transport sector, a continued reliance on domestic energy resources, principally coal. Under the baseline scenario, commercial energy consumption in China rises from around 1,000 mtce in 1990 to 3,300 mtce in 2020, with nearly 70 percent of energy in 2020 supplied by coal. In addition to potentially serious local environmental impacts, consumption of this much coal would result in roughly a tripling of China's GHG emissions compared to 1990. Without lowering economic growth, China's GHG

[3] Scenarios of economic growth and energy consumption have been generated in other parts of the overall China GHG Study. See the macroeconom.. analysis in Chapter 2, *China: Issues and Options in Greenhouse Gas Emissions Control, Summary Report*, December 1994.

emissions could be limited to a doubling between 1990 and 2020 if additional measures were taken to limit GHG emissions, including the rapid adoption of alternative energy technologies.[4] Details of the potential for alternative energy technologies and their costs are the subject of Chapters 2 and 3 of this report.

(1) Low-carbon substitutes for coal for electric power generation

1.5 The amount of electricity needed for the economy under the baseline scenario is estimated to be 1,300 TWh in the year 2000, and 3,850 TWh by the year 2020 (Table 1.2). In the year 2020, approximately one third of total commercial energy use, and around 40 percent of total coal use would be required to generate electricity under the baseline scenario. To meet the electricity demand of the baseline scenario would require the addition of around 700 GW of generating capacity between 1990 and 2020, or over 23 GW each year, requiring the annual completion of about 39 new 600 MW units.

Table 1.2 Electricity Generation and Installed Power Capacity: Current Levels and Future Scenarios [a]

Year	1990 actual	1993 actual	2000	2010	2020
Electricity generation (TWh)	621	836	1300	2430	3850
Installed capacity (GW)	138	183	290-295	525-540	825-870

a Electricity generation scenarios for 2000, 2010, and 2020 were estimated by the China GHG Model. See Ch. 2, *Issues and Options in Greenhouse Gas Emissions Control, Summary Report*, December 1994.

1.6 There are a number of low-carbon technologies that can be further developed in China to substitute for coal in the production of electric power. Chinese energy experts generally regard hydroelectric and nuclear power as the most promising low-carbon technologies for large-scale development in China in the near to medium-term.

- ***Hydroelectric power.*** China ranks number one in the world in hydroelectric resources, only a small portion of which has already been developed. In total, China's hydroelectric potential has been estimated at 380 GW, of which 70 percent is currently economic. In addition, there are 70 GW of mini-hydro sites available.

- ***Nuclear power.*** China has an active nuclear power program. The first nuclear plant in China, which was domestically designed and constructed, began operation in 1991. The first large-scale commercial nuclear facility began operation in 1994 in Guangdong Province. Including nuclear facilities under construction and planned, will

[4] The reduction potential and costs of options for reducing GHG emissions in China are given in the *Summary Report*, December 1994.

amount to about 4,500 MW by 2000 and 9,100 MW by 2005.

- ***Renewables.*** Other non-carbon technologies that can substitute for coal in electric power generation include wind, solar photovoltaic (PV), solar thermal, geothermal, and biomass (when grown on a sustainable basis). Table 1.3 shows current capacity and power production from alternative energy technologies in China.

Table 1.3 Potential and Current Development of Low-carbon Power Generation Technologies in China

	Resources (GW)	Installed Capacity (MW)	Power Generation (TWh)
Hydroelectric			
Large (>25MW)	380	44,600 (1993)a	169 (1994)
Small (<25MW)	70	11,790 (1989)b	31.6 (1989)b
Nuclear	--	2,100 (1994)a	13.5 (1994)a
Wind	200	17 (1993)a	--
Battery chargers		--	--
Grid-connected		13.4 (1993)a	--
Solar-PV	--	2.6 (1991)c; 3.3 (1993)a	--
Geothermal	1,000MW b	30 a	--
Tidal power	--	11 a	--
Biogas power	--	6 (1990)d	--
Biomass gasification	--	100 sets d	--

Sources: [a] Ministry of Electric Power, "Electric Power," 1994; [b] "The Development of New and Renewable Energy Resources in China," China Science and Technology Press; [c] Lin and Lee, "Report on Photovoltaic Generation," April 1993; [d] Energy Research Institute.

(2) Low-carbon substitutes for the direct use of coal

1.7 The direct use of energy currently accounts for about 80 percent of the energy consumed in China. Direct coal consumption can be divided into three types as shown in Table 1.4. Of the total energy currently consumed directly, 55 percent is coal, 16 percent is oil, and 27 percent is biomass. While the amount of energy used for power generation is expected to grow rapidly during the coming decades, non-power uses are likely to still account for the largest use of energy in China for the foreseeable future. According to the baseline scenario, the direct use of energy, mainly for industrial process heat, residential cooking and heating, and transport, will still account for two-thirds of primary commercial energy consumption in 2020. By 2020, the direct use of coal is estimated to be 1,800 million tons of raw coal. In the near term, the most promising energy sources in China for large-scale substitution of coal for direct use are natural gas (including gas from coal mines) and biomass.[5]

[5] While the net release of CO_2 from biomass burning will be zero if the biomass has been produced on a sustainable basis, there will generally be a release of other GHGs, such as CH_4, N_2O, NOx, and CO.

Table 1.4 The Direct Use of Coal in China

Type of Direct Use	Purposes Served	Potential Fuel Substitutes
High temperature heat	High temperature steam for industrial processes, and for kilns to produce cement and bricks	Natural gas, oil, biomass
Low temperature heat	Space and other heating for industry, commerce and households	Solar water heating, passive solar, geothermal, biomass
Cooking fuel	Cooking	Biomass, solar cooker, natural gas, and biogas

- ***Natural gas.*** There is significant potential in China for finding and developing low-cost sources of natural gas. In addition to oil and gas fields, natural gas from coal mines is also an economic energy resource in China; current reserves of coal-bed methane are large, however, only a small amount of the gas is currently being captured and used.

- ***Biomass.*** The direct consumption of biomass is a major fuel source in China, providing the majority of energy for rural households. Non-commercial biomass fuels, including fuelwood, crop residues and some animal dung, amounted to approximately 300 million tons of coal equivalent (mtce) in 1990. More efficient use of existing biomass resources, limitations on the overcutting of natural forests for fuelwood, and an expansion of fuelwood plantations under good growing conditions, could result in both a significant contribution to China's energy supply and a reduction in net CO_2 emissions.

- ***Other renewables.*** Other non-GHG emitting technologies that can substitute for coal in direct use include passive solar and solar thermal, wind, and geothermal energy. Though relatively small in comparison to total energy use, these renewable energy sources could be important for residential and commercial water and space heating, light industrial process heat, and water pumping, crop drying and crop processing in agriculture.

(3) Environmental impacts of coal use

1.8 The environmental effects of expanded use of coal in China will be severe unless measures are taken to switch fuels or mitigate emissions. While technologies exist to control the emissions of local pollutants, such as particulates (TSP), sulfur dioxide (SO_2), and nitrous oxides (NOx), there currently is no practical means of reducing CO_2 from coal consumption. CO_2 emissions, which may be contributing to global climate change through the "greenhouse effect," are the largest source of GHG emissions worldwide. According to the baseline scenario, China's CO_2 emissions would roughly triple between 1990 and 2020, making China the largest source of anthropogenic CO_2 worldwide. Mining, transporting, and burning additional quantities of coal will also have enormous consequences for air, water, and land quality. For instance, according to the baseline scenario, if there were no changes in pollution control technologies from 1990, TSP emissions would increase from 14 million tons in 1990 to 48 mt in 2020 and SO_2 emissions from 16 mt in 1990 to 55 mt in 2020. The reduction in TSP and SO_2 emissions by switching from coal to alternative energy sources will result in significant benefits by reducing impacts on human health, croplands, forests, and buildings and structures. While it is often difficult to quantify such benefits, they can and should be considered when assessing alternative energy projects.[6]

B. Methodology

1.9 In order to compare alternative energy projects with other GHG reduction options, a common method for calculating the net cost of reducing GHG emissions has been developed and used in the China greenhouse gas study.[7] In the case of alternative energy technologies, investment and per unit energy supply costs are compared to similar costs for coal. For instance, the investment cost (Y,$/MW) for a megawatt (MW) of wind-generated electric power capacity is compared to the investment cost for one MW of coal-fired capacity. Likewise, the levelized costs of wind-generated power (Y,$/KWh) are compared to the levelized costs of coal-generated power. It is also important to compare cost in terms of equal reliability and the time of delivery. For instance, the value of electricity varies during different times of the day and seasons of the year. To account for differences in reliability and time of service, additional capacity charges are added to alternative energy technologies, such as solar, wind and small-scale hydro, which exhibit intermittent availability. Assumptions regarding the operating efficiency, operating costs, investment costs, and CO_2 reduction potential of these technologies have been collected from both Chinese and international sources.

1.10 Background reports have been prepared on the current development of several low-carbon technologies that have particular potential for China, including wind, solar photovoltaic (PV), natural gas, and nuclear power. Since the development experience for these technologies has been considerably different in China and abroad, reports were prepared by both Chinese and international experts. International expert reports focused on recent commercial developments and the current and projected future costs

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[6] The human health benefits of reducing particulate and SO_2 emissions by improving energy efficiency were quantified in the cost-benefit analysis done in another component of the China GHG study. See subreport 8, *Valuing the Health Effects of Air Pollution: Application to Industrial Energy Efficiency Projects in China*, and subreport 4, *Energy Efficiency in China: Case Studies and Economic Analysis*.

[7] See Chapter 3, *China: Issues and Options in Greenhouse Gas Emissions Control, Summary Report*, December 1994.

of these technologies internationally, while the Chinese expert reports evaluated the current stage of development of these energy technologies in China.

1.11 Based on the background reports, Chinese experts prepared supply and cost scenarios for these and other alternative energy technologies in China for the years 2000, 2010, and 2050. This information was incorporated into an alternative energy model that calculates the incremental investment costs, and the CO_2 reduction associated with the alternative energy scenarios. Coal is assumed to be the swing fuel in the model. The amount of coal required is calculated by summing all other sources of energy supply, and then subtracting that sum from the total energy requirements as estimated in Table 1.2. In addition to a baseline, three other scenarios of alternative energy supply (AE-Min, AE-Mid, AE-Max) which reduce progressively more carbon, were also prepared for the years 2000, 2010, and 2050. To be consistent with the energy demand estimates from the overall China GHG study, alternative energy supply scenarios for the year 2020 were interpolated by using the average growth rate between 2010 and 2050.

1.12 Given the dominance of coal in China's economy, coal has been used as the reference for comparing the costs of alternative energy sources. In the analysis, the price of coal and the installed cost of coal-fired power plants have been raised to account for some of the negative environmental impacts associated with coal use. A premium has been added to the market price of Chinese coal and to the cost of coal-fired power generation equipment to allow for the removal, to international standards, of TSP and waste gases.

1.13 As noted above, most alternatives to coal that reduce CO_2 emissions also reduce other local air pollutants (e.g. TSP, SO_2, NOx). However, despite the local and global air pollution reduction benefits from low-carbon energy technologies, there can be negative environmental impacts associated with some of these technologies, costs which have not been explicitly calculated in this analysis. Therefore, prior to adopting low-carbon energy technologies for their global benefits, the environmental costs should also be assessed, such as resettlement and ecosystem damage associated with construction of hydroelectric projects; the hazards of LNG transport/distribution; local air pollution associated with biomass combustion; and the costs and risks of securing, storing, processing, or disposing of nuclear fuel.

2. ALTERNATIVE ENERGY OPTIONS FOR CHINA: TECHNICAL AND ECONOMIC ASSESSMENT

A. Introduction

2.1 For low-carbon alternative energy technologies to play a larger role in China's energy balance in the future, they must be able to substitute for coal both in the production of electric power and for direct use. For significant substitution to occur, not only must the technologies be proven, but their costs must be competitive with coal. China has an abundance of proven domestic coal reserves and relatively little proven oil and gas reserves; this is the primary reason coal is the least-cost option for many energy applications. Much of China's current energy-consuming capital stock, such as power plants, industrial boilers, and cooking stoves, have been designed to burn coal. While the continued growth of China's economy will result in a rapid turnover in capital stock in the future, the coal-specific infrastructure and technical expertise that China possesses will not be as easy to replace.

2.2 This section reviews China's experience in the use of low-carbon energy technologies. The discussion focuses on both technical and economic issues, with estimates made of current and projected future supply costs for low-carbon alternative energy technologies. The discussion begins with a review of coal. While China has considerable experience with the use of coal and hydroelectric power, and therefore both the technologies and the costs are well known, this is not the case for most all other low-carbon energy sources. Projecting future technology developments and future costs is an exercise fret with uncertainty. For comparison, international technical experience and international cost projections have been presented as well. The estimates of future supply costs in this chapter have been used in Chapter 3 to project estimates of the potential for low-carbon energy supplies in China and to estimate the overall cost of supplying a given amount of low-carbon energy.

B. Alternatives to Coal for Electricity Generation

2.3 Under all scenarios of future power generation undertaken for this study, the absolute amount of thermal power capacity in China will increase over the next 25 years. The extent to which low carbon-intensive fuels can be substituted for coal for power generation is related to upfront capital investment and capacity cost, and to the average cost of generating electricity for each of the alternatives.

(1) Coal-based Power Generation

2.4 **Technical Feasibility.** China has considerable experience in the production of coal-fired power plants, and until recently, relied entirely on domestic equipment for these plants. The existence of an extensive industrial infrastructure for producing coal-fired power generation equipment has implications for the cost of such facilities. Future plants are likely to be larger than the current facilities which are in the 200 to 300 MW range. China's current production of large coal-fired generating units, that is those over 600 MW, is limited. While China is able to produce much of the equipment for modern 600 MW plants domestically, high-temperature and high-pressure boilers and turbines are still largely imported.

2.5 Current operating efficiencies for domestically-built coal plants in China are low relative to rates achieved by modern international plants. Coal consumption for Chinese power plants averaged 427 gce/kWh in 1990. Because there are significant economies of scale in coal-fired power plants, coal consumption per kWh will be reduced in the future as China's stock of larger power plants increases. Chinese experts estimate future efficiencies of 350 gce/kWh in 2000, 340 gce/kWh in 2010, and 300 gce/kWh in 2050. By contrast, California assumes a heat rate of 9,800 to 10,500 Btu/kWh, which is equivalent to about 290 to 315 gce/kWh, signifying that the fuel efficiency estimates for China for future years are conservative.

2.6 **Economic Assumptions.** China has built and purchased numerous coal-fired generation plants, and therefore the uncertainty surrounding the costs of coal plants is low relative to other energy technologies. Because much of the equipment and engineering can be manufactured domestically, China is able to construct coal-based facilities at a considerable cost advantage compared to plants in other countries. According to Chinese estimates, investment costs for domestic coal-fired plants are around 2,600 yuan/kW (1990 yuan). In the future, an additional 15 percent will be required to meet stricter environmental regulations so that total investment is thus estimated at about 3,000 yuan/kW. Costs for coal-fired power plants in China with some foreign equipment and advanced environmental controls are in the range of 4,500 yuan/kW.[8] Based on these capital investment costs, and long-run costs for coal, the levelized generation costs for a coal-fired plant in China have been estimated in the range of 0.18-0.25 yuan/kWh (1990 constant prices) in 2020.

2.7 The Yangzhou power station includes state-of-the-art environmental controls, including electrostatic precipitators for particulate control (99+ percent removal efficiency) and low-NOx burners. Although there are no special SO_2 controls, the Yangzhou plant will burn low sulfur (0.3-0.4 percent) coal. Given the cost advantages

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[8] This estimates is based on the Yangzhou thermal power project in Jiangsu, financed in part by the World Bank. The coal plant at Yangzhou includes both domestic and foreign-produced equipment.

of Chinese domestic construction costs and components, the cost of the Yangzhou plant is still considerably below the investment cost figures assumed in the California Energy Commission.

Table 2.1: Cost Estimates for Coal-based Power Generation

	Joint Study Team Estimates (1990 prices) Yuan/kW	Joint Study Team Estimates (1990 prices) $/kW	California Energy Commission $/kW
Power Generation	2600	$553	
Transmission	700		
Environmental Equipment	350		
Coal Transportation	100		
Coal Mine Construction	750		
Total Investment Cost	4500	$957	$1237- $1636 (1989 prices)
Annualized Investment	610		202.5 -269.5 $/kW
Levelized Cost	0.2039 Y/kWh	0.0434 $/kWh	0.047 - 0.0742 $/kWh
Assumptions			
Annual Operating Hours	5000		5256-6570
Construction Period	3 years		5 years
Economic Life	25 years		30 years
Maintenance Ratio	3.5 %		20.2 - 24.5 $/kW
Fuel Cost (1990 prices)	146.5 Y/kW		0.0125 - 0.0176 $/kWh
Labor Ratio	1 %		.00058 - .00067 $/kWh

Sources: Joint Study Team; California Energy Commission (1993).

(2) Hydroelectric Power

2.8 **Technical Feasibility.** As is the case with coal-fired generation, China currently produces its own hydroelectric generating equipment and has a proven capability in the design and engineering of large and small hydro projects. Hydroelectricity currently accounts for about 24 percent of China's installed capacity and less than 20 percent of total kilowatt-hours produced. China is a world leader in the production of mini hydro equipment, defined here as those units less than 25 MW. China has already constructed more than 12,000 MW of mini hydro capacity.

2.9 **Economic Feasibility.** Hydroelectric cost estimates for China are based on considerable domestic experience. As with coal-fired units, investment costs in China for hydro are considerably below those in other countries. The joint Chinese-international expert team for this study estimates that on average the levelized cost of hydroelectric generation will rise to at least 0.30-0.35 yuan/kWh by the year 2020 for large-scale projects under the baseline alternative scenario. Since more than 70 percent of China's hydro resources are concentrated in remote regions of southwest China, where both construction and distribution costs will be higher, it is likely that an expansion of hydro capacity beyond the baseline will result in levelized costs at or above 0.35 yuan/kWh. While a number of these new hydro schemes may still be economically attractive due to system regulation and peaking capabilities, their costs are still substantially above the estimated levelized costs for coal for baseload generation. Table 2.2 and Table 2.3 show current cost estimates for hydro and mini-hydro projects.

Table 2.2: Hydroelectric Generation

	Joint Study Team Estimates (1990 prices) Yuan/kW	Joint Study Team Estimates (1990 prices) $/kW	California Energy Commission $/kW
Power Generation			
Year 2000	4360	928	
Year 2010	5230	1113	
Year 2020	6300	1340	
Transmission	1000	213	
Total Investment Cost			$1777 to $3442 (1989 prices)
Year 2000	5360	1140	
Year 2010	6230	1326	
Year 2020	7300	1553	
Annualized Investment Cost	(Y/kW/yr)		271.9-526.6 $/kW/yr
Year 2000	873		
Year 2010	1015		
Year 2020	1189		
Levelized Cost (1990 prices)	(Y/kWh)		
Year 2000	0.276	0.0586 $/kWh	0.0845 - 0.297 $/kWh
Year 2010	0.320	0.0681 $/kWh	
Year 2020	0.375	0.0798 $/kWh	
	Assumptions		
Annual Operating Hours	3800		3504 to 2190
Construction Period	6 years		5 years
Economic Life	50 years		50 years
Maintenance Ratio	2.0 %		53.8 - 58.4 $/kW/yr
Fuel Cost	0		0
Labor Ratio	0.4 %		0

Sources: Joint Study Team; California Energy Commission (1993).

Table 2.3: Mini-Hydroelectric Generation

	Joint Study Team Estimates (1990 prices) Yuan/KW	Joint Study Team Estimates (1990 prices) $/kW
Power Generation		
Year 2000	4500	957
Year 2010	5000	1064
Year 2020	5500	1170
Transmission	0	0
Total Investment Cost		
Year 2000	4500	957
Year 2010	5000	1064
Year 2020	5500	1170
Annualized Investment Cost	(Y/kW/yr)	
Year 2000	628	
Year 2010	698	
Year 2020	768	
Levelized Cost	(Y/kWh)	
Year 2000	0.278	0.0591 $/kWh
Year 2010	0.304	0.0648 $/kWh
Year 2020	0.331	0.0704 $/kWh
Assumptions		
Annual Operating Hours	2700	
Construction Period	3 years	
Economic Life	30 years	
Maintenance Ratio	2.0 %	
Fuel Cost	0	
Labor Ratio	0.4 %	

Sources: Joint Study Team; California Energy Commission (1993).

(3) Natural Gas-based Power Generation

2.10 **Technical Feasibility.** Electricity generation using natural gas is a proven technology that is simpler and cleaner than coal-based options. Natural gas contains about 40 percent less carbon than coal on an energy equivalent basis; even less carbon can be emitted given the higher efficiencies that can be achieved by natural gas power plants. Electricity generation by natural gas can be done using a single gas turbine or by combining a gas turbine followed by a steam turbine. This latter method, termed a combined-cycle facility, can achieve an overall efficiency above 45 percent. This higher efficiency, along with short lead times for plant construction, plant modularity, modest capital investment, plant reliability, relatively low cost sources of natural gas, and lower air pollution emissions, have made gas-fired combined-cycle plants the preferred choice for new baseload and peaking power facilities in the U.S., Canada, and other countries with abundant gas supplies.

2.11 Unfortunately, proven natural gas reserves in China are modest, and natural gas production in China is insufficient to meet current industrial and residential demand. Therefore, if natural gas is to replace coal-based electric power generation in China, vast new domestic reserves must be found or the gas associated with coal mines must be recovered and used to a much larger extent than it is now. Some additional gas may become available through importation. The most likely scenarios for importation would be liquefied natural gas (LNG) by sea or the construction of long-distance overland gas pipelines from Russia or central Asia. Even if long-distance pipelines are built, in the short term, the highest-valued use of the gas will probably not be the electric power sector. The analysis here assumes that LNG would be the primary source of gas for power generation.

2.12 LNG is natural gas that has been cooled to -260 °F to reduce its volume to 1/600th, thus allowing for storage and transport in relatively small containers. The technology for producing and transporting LNG is capital-intensive and characterized by economies of scale. Modern LNG projects are never less than 250-300 MMcf/d, equivalent to about 2.8 bcm per year. For comparison, China's current annual production of natural gas is about 15 bcm.

2.13 Presently, Japan and other Asian countries are the primary consumers of LNG worldwide; in 1990, Japan alone accounted for 66 percent of world LNG consumption; 5,425 million cubic feet per day (MMcf/d) or about 56 billion cubic meters (bcm) per year. To become an importer of LNG, China would have to compete with Japan, South Korea and Taiwan for any new LNG contracts. While the demand for LNG has been growing in the Asia region, production from the region's largest LNG producer, Indonesia, has been declining.

2.14 **Economic Assumptions.** The costs of generating electricity with natural gas in China are highly dependent on the source of the gas. The cheapest source of gas will be domestic on-land reserves close to consumption centers. However, proven gas resources in China are very limited compared to both coal and petroleum. For both domestic and imported gas, there is the issue of whether electric power generation is the highest-valued use of natural gas in China. Levelized costs for LNG-generated electric power in other Asian countries are currently as low as 0.05 $/kWh, which would make it one of the lower-cost alternative sources of energy for power generation in China, particularly in areas of the country far from coal reserves such as the southeast coast.

2.15 To produce and deliver LNG requires a liquefaction facility, loading terminals, tankers, unloading port facilities, regasification plant, gas pipeline, and gas-fired electric generating plant. The liquefaction facility and loading port facilities would generally be built and owned by the gas producer. Ownership of the tankers and even the unloading port facilities may be owned by China or the supplier. In the latter case, a higher fuel cost would be required, though China would not have to raise as much capital. Because of the large fixed capital assets that are required for LNG for both the producer and consumer, contracts tend to be long-term and guaranteed by governments.

2.16 The Chinese team based their cost estimates for LNG on a facility built in Taiwan, which has high costs per KW for the receiving station and the pipeline. The international expert report estimates that the costs for a receiving station could be considerably less (see Table 2.5). The site and size of the facility are critical for the cost of the receiving station, as shown in Table 2.4. At the low end, small European terminals have recently been built for $240 million. A new port facility and accompanying infrastructure may cost at least $700 million.

Table 2.4: LNG Receiving Terminal Costs (Million US$ (1992))

Terminal Size BCM/Y	Low Range	Medium Range	High Range
1.3-1.50	220-260	340-350	500-7000
2.5	240-270	350-360	700-800
5	270-300	350-370	700-800

2.17 The largest costs for LNG are the costs of liquefaction, which are assumed here to be borne by the producer. A 500 MMcf/day facility is likely to cost upwards of $2 billion. To minimize capital costs for China, the LNG project might be structured so that the liquefaction capital costs are absorbed by the gas producer or the project consortium and the Chinese would only pay a charge, based on volume throughput, for liquefying the gas. If this is the case, the capital costs to China would be for the regasification plant, storage, and the pipeline connecting the plant to the main transmission line or to a power plant.

2.18 A 500 MW combined-cycle plant would consume approximately 0.5 bcm/year, or put another way, a 5 bcm/yr LNG facility would be adequate to support 5,000 MW of baseload electric capacity. The capital costs of the receiving facility are around $70 KW in the medium cost case, and $140 KW in the high case. The cost of the combined-cycle generation facilities now being installed in the developed countries are in the neighborhood of $600 to $750/KW ($1990). The California Energy Commission assumes costs for a similar combined cycle facility at $525 - 800/KW ($1989). Pipeline costs would also vary by terrain, cost of the right-of-way, size of line, number of river crossings, cathodic protection, safety requirements, source of steel, access to the route, and compression.

2.19 The price of LNG, which is related to crude prices, has dropped from the high prices of the early 1980s. In 1981, the price of LNG imported by Japan averaged $5.83/Mmbtu, while in 1991 the price was only $3.98/MMbtu. The price that China pays for LNG depends on whether China buys it own transport ship or whether China contracts others to ship for them. For this analysis, it is assumed that China is buying LNG delivered at the spot market price. The current price is around $3.50 to $4.00 per MMbtu ($1990).

Table 2.5: Imported Liquid Natural Gas

	Chinese Experts (1990 prices) Yuan/KW	International Expert Report Yuan/KW	International Expert Report $/KW	California Energy Commission[a] $/kW
Power Generation	1900	2800	$600-$750	$525-800 (1989 prices)
Transmission	500	500	$106	
Receiving Station	4950	330	$70-140	
Gas Pipeline	550	550	$60-120	
Total Investment	7900	4180	$836-1116	$525-800
Annualized Investment	1007	645-855	$137-182	$86-131
Levelized Cost	0.4129 Y/kWh (0.088 $/kWh)	0.27-0.32 Y/kWh	0.058-0.068 $/kWh	0.043-0.049 $/kWh
	Assumptions			
Annual Operating Hours	6000	6000	6570	6570
Construction Period	5 years	5 years	5 years	5 years
Economic Life	25	30 years	30 years	30 years
Maintenance Ratio	1.5 %	0.07 Y/kWh	0.015 $/kWh	3.88 $/kW
Fuel Cost	1320 Y/kW	0.11 Y/kWh	0.023-0.026 $/kWh	0.025 $/kWh
Labor Ratio	0.4			.0039 $/kWh

a Costs are without an LNG receiving station.

Sources: Joint Study Team; California Energy Commission.

(4) Nuclear Power

2.20 Many Chinese energy experts conclude that the development of nuclear power is the best option for power generation in some parts of China given the lack of other large-scale alternatives and the difficulties and costs of transporting coal from inland mines to high-demand coastal areas such as the Southeast.

2.21 **Technical Feasibility.** The development of nuclear power, once thought to be the path to inexpensive electricity, has slowed considerably around the world. Orders for new nuclear plants worldwide, which reached 30-40 GW per year in the 1970s, dropped to around 4-5 GW per year as of the late 1980s. Today only a few countries outside the former Soviet block, specifically Japan, France, South Korea, China, and India, have active nuclear construction programs. Collectively there is very little experience with nuclear generation in developing countries; only China, India, and South Korea have ordered new plants since 1982.

2.22 China has an active nuclear power program and is likely to have a capacity of around 4,500 MW by the end of the century. The 300 MW Qinshan nuclear plant, near Shanghai, was domestically designed and constructed and began operation in December 1991. The two 900 MW units at Daya Bay in Guangdong Province began operation in 1994. The Daya Bay plant is the first large-scale commercial nuclear plant built in China. Additional units with a combined capacity of 2,400 MW are planned to begin construction soon at these two sites and an additional 4,000 MW nuclear power facility is planned for Yangjiang, Guangdong Province, to be completed by the year 2005.

2.23 Economic growth and the impending shortage of electric power capacity at the end of the decade in the United States and other countries may portend a reemergence of the nuclear power industry. Restrictions in the use of coal, combined with stricter environmental requirements for air pollution, may lead some electric utilities to reconsider the nuclear option. It is hoped that new, safer, and less costly nuclear-based technologies will emerge. However, investment in research and development of these new technologies has been reduced in many of the same countries that are reconsidering their nuclear programs.

2.24 **Economic Assumptions.** There are vast differences of opinion surrounding the costs and expansion capabilities of the nuclear power industry in China. Chinese nuclear proponents anticipate that capital costs will fall to 6,500 yuan/kW (US$1,180/kW in US$1990) by the year 2020 as China develops its own nuclear production industry. However, even with such low estimates, the levelized costs of nuclear power are 40 percent above the high estimates for modern coal-fired baseload generation in 2020. If the cost estimates of the international experts participating in this study (US$1,900-2,700/kW) prove more accurate, nuclear power would be too expensive to be competitive with coal in China.

2.25 The key variables affecting nuclear power costs are: capital costs, fuel and operation and maintenance (O&M), and plant availability. Cost and operating efficiency figures provided by the various sources are shown in Table 2.6.

- ***Capital Costs.*** The Chinese expert report used the experience of China's two recently completed nuclear plants and contract prices for a plant to be built by the Chinese in Pakistan to estimate costs. Given the variation in nuclear costs worldwide, the Chinese expert group modified this cost estimate. The Chinese estimate used in Table 2.6 is half-way between the cost estimates provided in the Chinese expert report and the estimate provided by the international expert. The capital cost estimate is lowered to a value of 5,800 Yuan/kW by 2050, which is equivalent to the estimated cost of the Qinshan plant. The estimates by Desai combine actual United States plant costs, which are the only source of reliable statistics, with projected future costs for the US and other countries.

- ***Fuel , Operation and Maintenance Costs.*** Fuel costs for nuclear plants are lower than for fossil-fuel based plants. The price of uranium has varied considerably over the last 25 years and lends a degree of uncertainty to future cost projections. The spot-market price for yellow-cake has dropped from over $110/kg in 1978 to less than $20/kg in mid-1992. This 90 percent decrease in the real price of uranium is the result of the development of new sources of uranium and a slower than expected demand. While the price of uranium is expected to increase by the turn of the century, the security of uranium supply is no longer considered a major concern (Desai,1992). Figures for China's reserves of uranium are not well documented. However, the low scenario of nuclear capacity in China in the year 2050 would require over one-quarter of proven worldwide reserves of uranium that could be extracted at a cost of $130/kg or less. The high scenario of nuclear capacity in China in the year 2050 would require most of the world's proven reserves, even excluding similar increases in nuclear programs elsewhere.

- ***Plant Availability.*** The cost-effectiveness of nuclear plants is affected by the plant availability. As in the capital cost values, data for plant performance varies by reactor type, reactor size, suppliers, vintage, age, country or region, prior nuclear operating experience, and calendar year-to-year variations due to refueling outages, unusual inspections, and/or major retrofits. The 6000 hours assumption listed in Table 2.6 represents a 68 percent capacity factor, which is similar to the average level achieved by pressurized light-water reactors worldwide.

Table 2.6: Nuclear Power Development

	Joint Study Team Estimate (1990 prices) Yuan/KW a	Joint Study Team Estimate $/kW	International Expert Report (1992 prices) $/kW	California Energy Commission $/kW
Power Generation	7800 5800 (2050)	1660 1234	Unit 1 $700-2600 Unit 2 $360-2080 Unit 3 $190-1820	$2635 (in 1989 prices)
Transmission	700			
Total Investment Cost	8500 6500 (2050)	$1809 $1383	$2635	$2635
Annualized Investment	1732 1325 (2050)			582.23 $/kW
Levelized Cost (Y/kWh)	.4249 .3422 (2050)	.0904 .0728	0.09- 0.14 $/kWh	0.110-0.136 $/kWh
		Assumptions		
Annual Operating Hours	6000			5256 - 6570
Construction Period	9 years			10 years
Economic Life	30 years			40 years
Maintenance Ratio	2.3 %		0.015-0.03 $/kWh	20.86 $/kW
Fuel Cost	440 Yuan/kW		0.007-0.01 $/kWh	0.0053-0.00787 $/kWh
Back-end fuel cycle and decommissioning			0.003-0.006 $/kWh	
Labor Ratio	0.4 %			.01334 $/kWh

a Value used is 50 percent of Chinese nuclear team estimate of 5500 Yuan/MW and 50 percent of international estimate of 2150 $/kW.

(5) Wind Turbine Power

2.26 **Technical Feasibility.** Wind power is a very attractive substitute for carbon-based fuels, since there are few negative externalities associated with its use. Wind turbine power generation is one of the most proven renewable energy technologies worldwide and is developing rapidly. Its technical feasibility has already been demonstrated in China and throughout the world. There is currently over 2,000 MW of wind-generated capacity worldwide, and in some situations, wind is the least-cost option for electricity production. China currently has 9 MW of installed grid-connected wind power, 5 MW of which are Chinese built wind farms using domestic technology.

2.27 China has been developing and installing a large number of small (100W-7.5kW) wind turbines for individual use in certain rural areas, most notably in Inner Mongolia. Small wind turbine technology is proven in China and the reliability is increasing. China is also improving the technical support network necessary to improve sales and maintenance. China has not been as successful in producing its own medium to large-scale wind turbines. China has produced a number of units which are currently on-line, which range in power from 20 to 350 kW. These units are generally more expensive and less reliable than advanced imported equipment. China has imported a variety of turbines, as well as produced some turbines using European technology. These units have not only contributed to China's electric supply, but have assisted China along the learning curve in producing their own turbines with better quality and in greater quantities.

2.28 **Economic Assumptions.** Table 2.7 and Table 2.8 show the economic calculations for grid connected wind turbines and battery charger wind turbines in China. Grid-connected systems are most useful in remote areas with current electricity shortfalls. Many of these areas also have good wind resources. Wind energy for power generation is generally more expensive than grid-based electricity generation, but in remote areas is less costly than many other options, such as diesel generators. The cost of transmission lines will preclude connection of many rural areas in China in the near term, making small wind generators an important technology for rural electrification. The current cost needed to recoup investment for wind-generated electricity in China is about 0.3 Yuan/kWh. However, it is assumed by Chinese energy experts that grid connected wind would require 92 percent of additional firm capacity to meet peak demands, which raises the levelized cost to more than 0.5 Yuan/kWh. Even with the additional charge for back-up capacity, the cost of wind-generated power is estimated to fall to around 0.3 Y/kWh by the year 2010, which makes it one of the least cost non-carbon alternatives for power generation in China.

2.29 Wind farms in the U.S. in the 50 to 100 MW scale are being installed for as low as $700/kW. At this cost, wind generated electricity would be in the range of 0.04 $/kWh, which could be competitive with coal under conditions of equal reliability. Chinese experts estimate that wind-powered electricity generation would cost in the range of Y7,000-10,000/kW (US$1,490-2,130/kW). Factors raising the current cost of wind farms in China are that the scale of wind farms is smaller and that Chinese-manufactured wind turbines (20-350 kW) are not as big as foreign designs. The key to lowering the installed costs of wind turbines in China in the future is to improve domestic turbine designs to make them larger and more reliable, to capture scale economies by establishing larger wind farms, and to select sites where wind regimes and power system characteristics minimize requirements for back-up capacity. At the low end of the range for installed costs, wind power is likely to be competitive with coal-fired power generation.

Table 2.7: Grid-Connected Wind Turbine Generators

	Joint Study Team Estimate (1990 prices) Yuan/KW	Joint Study Team Estimate $/kW	California Energy Commission $/kW
Power Generation			
Year 2000	6660	1417	
Year 2010	5500	1170	
Year 2020	5000	1064	
Transmission	500	106	
Total Investment Cost			$787 (1989 prices)
Year 2000	7160	$1523	
Year 2010	6000	$1277	
Year 2020	5500	$1170	
Annualized Investment (Y/kW/yr)			101.40 $/kW
Year 2000	959		
Year 2010	803		
Year 2010	736		
Levelized Cost (1990 prices)	(Y/kWh)		0.0556-0.0593 $/kWh
Year 2000	0.408		0.0868 $/kWh
Year 2010	0.318		0.0677 $/kWh
Year 2020	0.273		0.0581 $/kWh
	Assumptions		
Annual Operating Hours			2190
Year 2000	2700		
Year 2010	2900		
Year 2020	3100		
Construction Period	1 year		1 year
Economic Life	20 years		30 years
Maintenance Ratio	1.5 %		0
Fuel Cost	0		0
Labor Ratio	0.5 %		.00926-.013 $/kWh

Table 2.8: Battery-Charger Wind Turbines

	Joint Study Team Estimate (1990 prices) Yuan/KW	Joint Study Team Estimate $/kW
Power Generation		
Year 2000	10000	$2128
Year 2010	10000	$2128
Year 2050	8000	$1702
Transmission	0	0
Total Investment Cost		
Year 2000	10000	$2128
Year 2010	10000	$2128
Year 2050	8000	$1702
Annualized Investment Cost	(Y/kW/year)	
Year 2000	1770	
Year 2010	1770	
Year 2020	1416	
Levelized Cost (1990 prices)	(Y/kWh)	
Year 2000	0.6838	0.1455 $/kWh
Year 2010	0.6838	0.1455 $/kWh
Year 2020	0.5300	0.1128 $/kWh
	Assumptions	
Annual Operating Hours		
Year 2000	3100	
Year 2010	3100	
Year 2020	3200	
Construction Period	1 year	
Economic Life	10 years	
Maintenance Ratio	3.0 %	
Fuel Cost	0	
Labor Ratio	0.5 %	

(6) Biomass

2.30 The direct combustion of biomass materials for energy is common and widespread in China. The major forms of biomass burned are agricultural crop residues (stalks, husks, leaves) and firewood; only a small portion of animal wastes (dung) are currently used for fuel. Biomass is used by rural households primarily for cooking and heating. A small amount of biomass is currently being liquified in China on an experimental basis for use in electricity generation. Chinese energy experts estimate that direct combustion of biomass will decline as liquefied natural gas and gasified biomass use becomes more popular. Larger scale usage of gasified biomass is also expected to increase for uses such as central heating districts and hot water supply systems. Table 2.9 identifies cost estimates for construction and operation of a biomass gasification power station.

Table 2.9 Costs for Biogas Power Stations

	Joint Study Team Estimate (1990 prices) Yuan/KW	Joint Study Team Estimate $/kW	California Energy Commission $/kW
Power Generation	1000	$213	
Biogas Production	4000	$851	
Total Investment Cost	5000	$1064	$1140 - $2280 (1989 prices)
Annualized Investment Cost	620.72		146.97 -293.81 $/kW
Levelized Cost	0.3604 Y/kWh	0.0767 $/kWh	0.0627 - 0.0963 $/kWh
Assumptions			
Economic Life	30 years		30 years
Maintenance Ratio	1.50 %		0.00 %
Fuel Cost	0		0.0339 $/kWh
Labor Ratio	0.5 %		.00645 $/kWh

Source: Chinese study team and California Energy Commission.

(7) Solar photovoltaic (PV)

2.31 **Technical Feasibility.** Photovoltaic cells are made from a semiconductor material which converts sunlight to electricity by separating negatively-charged electrons from positively charged holes. Numerous semiconductor materials have been tested. Conversion efficiencies and production costs vary. The individual cells are joined together into a module and the modules are joined to form a larger array. Worldwide, over 200 firms produce PVs. Worldwide shipments of PVs reached 55.3 MW in 1991 (California Energy Commission, 1992).

2.32 Widescale commercialization of PV will require that cell production and assembly move from small batch, manual production to fully automated manufacturing. It is assumed that increased orders for PV cells will allow the industry to develop newer production techniques. Several countries have developed programs to promote development by creating a market for the cells.

2.33 Effort is also concentrated on improving the efficiency of cells; ie., the rate at which they convert sunlight into electricity. Laboratory tests have created cells that achieve efficiencies of 23 percent and 32 percent using concentrators to increase available sunlight. In commercial production, efficiencies have reached 13 percent for flat plat modules and 17 percent for concentrators. The California Energy

Commission projects that commercial efficiencies could reach 18 percent for flat plate and 25 percent for concentrators by 2010 to 2030. The Chinese expert team assumes that China's PVs will also reach a 18 percent efficiency for crystalline silicon cells by the year 2050. They also project that thin film cells of either amorphous silicon or CuInSe2 (CIS) and CdTe will reach 15 percent.

Table 2.10 Costs for Photovoltaics Power Stations

	Joint Study Team Estimate (1990 prices) Yuan/KW	Joint Study Team Estimate $/kW	California Energy Commission $/kW
Power Generation (1989)			
1989			3650 to 4860
2000	20,000 to 28,400	$3636 to 5164	1940 to 3650
2010	10,500 to 19,800	$1909 to 3600	1200 to 2190
2020	6540 to 8350	$1391 to 1777	--
Annualized Investment Cost			
1989			507 to 675 $/kW
2000	2483-3526		270 to 507 $/kW
2010	1304-2458		167 to 304 $/kW
2020	812-1037		--
Levelized Cost (Y/kWh)		($/kWh)	
1989			0.233 to 0.310
2000	1.23 to 1.74	0.261 to 0.371	0.124 to 0.233
2010	.645 to 1.22	0.137 to 0.259	0.077 to 0.140
2020	.402 to .513	0.086 to 0.109	--
Assumptions			
Annual Operating Hours	2200		2190
Construction Period	1 year		1 year
Economic Life	30 years		20 years
Maintenance Ratio	1.00 %		0.00 %
Fuel Cost	0		0
Labor Ratio	0.1 %		.0008-0.0016 $/kWh

2.34 **Economic assumptions.** Technical improvements in photovoltaic electric generation over the past 20 years have resulted in a steady decrease in installed costs. As a result, solar photovoltaics have become economic in remote locations in developed and developing countries. The whole future of PVs depends on the reduction in the capital costs associated with their production. There have been significant reductions in costs over the last ten years. For example, the module price for crystalline silicon has dropped from 120 Yuan/W in 1978 to around 20 Yuan/W in 1992. These improvements in the efficiency of solar cells and the costs of assembly and associated equipment have lowered installed costs to $0.25 to $0.50/kWh. Still, the cost of electricity from solar PV is more than four times current average US and Chinese conventional power generation cost levels. The prospects for the future depend on a 5 to 10-fold reduction in costs. Such reductions will require that cell production and assembly move from small batch, manual production to fully automated manufacturing. Even with the most optimistic of assumptions for the next century, experts expect PV-generated electricity in China to be twice the cost of coal-generated electricity.

(8) Solar Thermal Power

2.35 **Technical Feasibility.** Test facilities of solar thermal power generation are now operating in the US and Europe. System sizes have increased from 13.8 MW to 80 MW, and installed cost per kW have dropped from $4,500 to $2,875 kW. A report by the US Department of Energy (1990) suggests several key steps to improve the efficiency and cost of central receiver power plants. Short-term improvement for the first 100 MWe central receiver plant, including low-cost membrane heliostats and reduced receiver cost for an advanced nitrate salt receiver should lower costs by 24 percent. Medium term improvements associated with the fifth central receiver plant, the first 200 MWe power plant would lower costs by 45 percent. This plant would use an advanced salt-in-tube receiver. The ultimate central station, assumed to be the sixth power plant in this development scheme, would use a direct absorption receiver and mass-produced stretched membrane heliostat concentrator, and achieve a cost reduction of 60 percent over current technologies.

2.36 Similar projections are made for parabolic-dish power plants. These systems are 25 kWe modules that will hopefully be mass-produced. The chief technological improvements will be the development of large area, single facet, stretched membrane dishes, 25 to 30 kWe advanced Stirling engines, and a reflux boiler or heat pipe receiver.

2.37 **Economic Feasibility.** As was the case with PVs, the key requirement for the significant reductions in solar thermal system costs will be the rapid increase in the number of units produced. Mass production of the heliostats or the parabolic dishes will only result if substantial demand for these products exist. The projected reductions assume aggressive government support and utility sponsorship. Table 2.11 presents the various cost estimates.

Table 2.11 Costs for Solar Thermal Power Stations

	Joint Study Team Estimate (1990 prices) Yuan/KW	Joint Study Team Estimate $/kW	California Energy Commission $/kW
Power Generation			
1989			2,670 - 2,860
2000	13,200	$2400	--
2010	10,000	$1818	2,445 - 2,595
2020	7600	$1381	--
Annualized Investment Cost			
1989			387 - 415
2000	1,988		--
2010	1,506		354 - 376
2020	1,144		--
Levelized Cost (Y,$/kWh)			
1989			0.122 - 0.131
2000	0.927	0.197	--
2010	0.702	0.149	0.069 - 0.073
2020	0.534	0.114	--
Assumptions			
Annual Operating Hours	2500		3,513 - 5,519
Construction Period	3 year		3 years
Economic Life	20 years		30 years
Maintenance Ratio	2.00 %		26 - 47 $/kW
Fuel Cost	0		0
Labor Ratio	0.5 %		0

(9) Geothermal

2.38 High-temperatures (above 150°C) are generally needed for geothermal power generation. High-temperature geothermal resources in China occur primarily along the southeast coast (Fujian, Guangdong, Taiwan) and in the southwest plateau (southern Tibet, western Yunnan and western Sichuan). A number of experimental geothermal power facilities have been built in China utilizing low temperatures (< 100°C), including plants in Guangdong, Jiangxi, Hebei and Hunan. Two high-temperature geothermal power stations have been built in Tibet: Yangbajing, with an installed capacity of 19 MW, and Langjiu with a capacity of 1 MW. Shallow well temperatures at Yangbajing have been measured at 145-172°C, while a temperature of 202°C was measured at a depth of 1000 meters in 1988. Other potential areas for geothermal power development in China are in Yunnan, and in the East Taiwan geothermal zone.

2.39 Although geotherm.'-based electricity generation may play an important role in power generation in some parts of China, such as Tibet, geothermal power will not provide significant amounts of power for the country as a whole. If all potential resources were developed, geothermal power would amount to about one-half of one percent of China's current installed power capacity. The cost assumptions for geothermal are presented in Table 2.12.

Table 2.12 Costs for Geothermal Power Stations

	Joint Study Team Estimate (1990 prices) Yuan/KW	Joint Study Team Estimate $/kW	California Energy Commission $/kW
Power Generation (1989)	7,000	1,675	2,400 to 3,000
Annualized Investment Cost	1156		347 to 449
Levelized Cost (Y,$/kWh)	0.364	0.0773	0.060 to 0.094
	Assumptions		
Annual Operating Hours	5,000		5,256 to 6,570
Construction Period	3 year		3 years
Economic Life	15 years		30 years
Maintenance Ratio	7.40 %		47 $/kW
Fuel Cost	0		0
Labor Ratio	1 %		0

C. Alternatives as a Direct Substitute for Coal

2.40 In addition to coal, China currently uses oil, natural gas, and biomass fuels as direct energy sources. Under the baseline GHG scenario, China will require about 2 billion tce in the year 2020 for non-power energy applications, including transport, residential cooking and heating, and industrial process heat. It is assumed in the analysis that petroleum will be used almost exclusively in the transport and petrochemical sectors. Fuel for direct use in the residential and industrial sectors will include coal, gas, and renewables such as solar and fuelwood.

(1) Biomass

2.41 Non-commercial biomass fuels, including fuelwood, crop residues and some animal dung, amounted to approximately 300 million tons of coal equivalent (mtce) in 1990. As much as half of the estimated 150 mtce of fuelwood consumed in China is obtained from the overcutting and destruction of natural forests and is therefore not sustainable. If new sources of biomass for fuel can be produced on a sustainable basis, there will be no net CO_2 emissions since the carbon released during combustion will not exceed the amount absorbed by the plant during its life. Depending on the technology used, biomass fuel combustion can produce other GHG emissions besides CO_2. For instance, biomass burning resulted in emissions of about 3.6 million tons of methane, and 0.05 million tons of N_2O in 1990, equivalent to 10 percent and 19 percent, respectively, of total national emissions of these GHG gases.[9]

2.42 **Fuelwood.** Unlike most other alternative energy sources, the costs of producing fuelwood in China can be lower than coal on an energy equivalent basis. Based on an economic analysis of fuelwood plantations in which fuelwood is grown under good conditions and intensive management, the discounted cost of producing a ton of fuelwood was found to be 119-245 Y/tce compared with coal at about 160 Y/tce.[10] The region where fuelwood production costs are lowest is South China, where costs range from 119-141 Y/tce. However, the current price of fuelwood sold by state forest farms in China is only about 90 Y/tce, which is below the break-even price calculated for fuelwood plantations in all regions of China. If fuelwood were used to a larger extent in China for commercial purposes, such as tobacco and tea drying, or power generation, fuelwood plantations would have a ready source of funds for development and a true market price for fuelwood could develop. While strong commercial demand would aid in the development of fuelwood plantations, Chinese foresters argue that strong demand and higher prices make it even more difficult to protect natural forests from illegal felling; protection of forests has been the major reason for government support of fuelwood plantations.

(2) Natural gas

2.43 Because of its convenience and higher end-use efficiency, natural gas is highly valued in China as a residential cooking fuel. Given its cleanliness, natural gas will become even more important as a substitute for coal for environmental reasons, particularly in urban areas. Development costs of new gas finds are uncertain at this point. If environmental benefits are considered, the highest-valued use of natural gas is expected to be in the residential sector and, depending on the amount of domestic gas that is discovered, this may preclude much natural gas being used by the power sector.

2.44 **Coal-bed methane.** Methane from coal mining represents one of China's best alternative energy options that can be developed in the short-term. Eçonomic analysis of various uses of coal-bed methane carried out under a GEF technical assistance study[11] conclude that the highest valued use of the gas is as a substitute to coal by coal mines and their immediate locality. Other uses, including piping of the gas to nearby cities for residential consumption and on-site electricity generation, also show rates of return above 12 percent at current market prices for gas, coal, and power. The main barriers to the development of coal-bed methane have been low gas prices and a lack of domestic technical expertise in gas recovery and processing. The reform of natural gas

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[9] See Subreport 1, *Estimation of Greenhouse Gas Emissions and Sinks in China, 1990*, August 1994.

[10] The costs of producing fuelwood are detailed in Subreport 6, *Greenhouse Gas Emissions Control in the Forestry Sector*, November 1994.

[11] *Coal-bed Methane in China*, GEF Technical Assistance Study.

prices in China since 1990 has led to an increase in the amount of coal-bed methane recovered. This trend is likely to continue given the local environmental benefits of gas use and the high willingness to pay for gas by residential consumers.

(3) Other: solar, wind, and geothermal

2.45 Renewable technologies for non-power applications, including passive solar energy, solar cookers, solar water heating, and geothermal heating, can play an important energy supply role in China in the future, particularly in the residential sector. Nonetheless, even under optimistic assumptions, these technologies are not expected to account for a large percentage of China's total energy supply.

2.46 In rural areas not connected to an electric power grid, wind can be a low-cost source of power for agricultural, residential and light industrial purposes. Solar, both active and passive, could play an important role in residential water heating and space heating/cooling in China. There are reportedly about 2 million residential solar water heaters in China today and another 500,000 domestically-produced units are being sold annually. Although precise cost information on solar water heaters produced in China is not available, domestic units are likely to be competitive in certain parts of China, and with further development, their use could be expanded in the residential-commercial sector and in some industrial process heat applications. One of the drawbacks of solar and wind energy which increases their costs, is that back-up capacity may be needed, particularly for commercial and industrial applications.

3. FUTURE ROLE OF ALTERNATIVES IN CHINA

3.1 Greenhouse gas emissions in China can be substantially reduced by lowering the carbon-intensiveness of China's energy supply mix. However, over the short term, there are limits on the extent of substitution away from coal due to the long lead times needed to develop alternative technologies, the abundance of low-cost coal in China, and because of the sheer magnitude of energy supply that will be needed to fuel China's economic expansion. A baseline energy use scenario to the year 2020 has been generated as part of the overall China greenhouse gas study. (see Table 3.1) This scenario assumes relatively rapid economic growth and continued improvements in energy efficiency. Total primary energy use expands over three-fold between 1990 and 2020 under the baseline scenario with a roughly comparable expansion of GHG emissions.

Table 3.1 Baseline commercial energy use scenario, 1990-2020

	1990	2000	2010	2020	Average annual growth rate, 1991-2020
Total primary energy use (mtce)	987	1,560	2,380	3,300	4.1
Electric power use (TWh)	623	1,300	2,430	3,850	6.3
Per capita energy use (kgce)	863	1,200	1,700	2,280	3.3

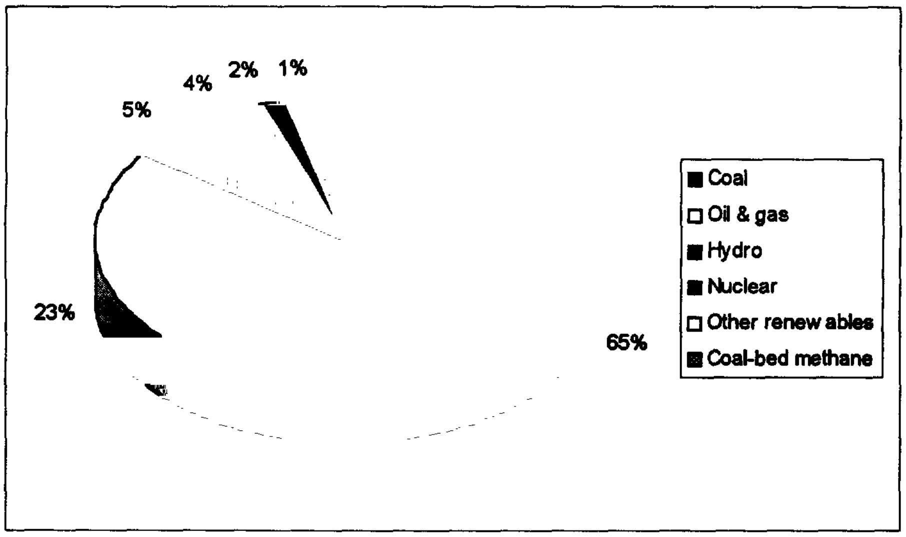
Source: *China: Issues and Options in Greenhouse Gas Emissions Control, Summary Report*, December 1994.

3.2 The only low carbon-intensive fuels that are expected by most experts to supply an appreciable incremental amount of energy over the medium term (to 2010) in China are hydro for power generation, and biomass, natural gas, and coal-bed methane as direct substitutes for coal. By the year 2020, nuclear, wind, and solar could also provide significant amounts of low-carbon energy, particularly for electric power generation. The key issue for the expansion of low-carbon energy sources beyond the baseline scenario is cost. Nonetheless, over the long term, the only option for significantly reducing GHG emissions in China is the adoption of alternative energy supplies.

A. How Much Alternative Energy Can be Supplied?

3.3 Under the baseline scenario, coal, petroleum, and gas (including coal-bed methane) account for nearly 90 percent of China's total energy supply and around 77 percent of total electricity generation in 2020. Under the baseline, alternative energy supplies are used exclusively for electricity production. In addition to the baseline scenario, the joint study team generated three other coal substitution scenarios to reflect increasing amounts of alternative energy supplies that could be developed in China by the year 2020.[12]

Figure 3.1 Baseline energy supply scenario, 2020



3.4 **Short- to medium-term.** The mix and quantities of energy resources that could be developed on a large scale before 2010 are limited to those that are already available in China or could be easily imported from abroad. Coal is projected to continue to be the primary fuel for electric power generation and as a direct fuel. Table 3.2 shows the amount of coal substitution available in the electric power sector by the year 2010 under the baseline and most the aggressive substitution case (AE-Max). The limitation on the expansion of alternatives for power generation over the short- to medium-term is due to: (i) the substantial lead times that are needed for capital-intensive projects such as hydro and nuclear power, and (ii) the fact that some alternatives may not be fully commercial before 2010. Hydroelectricity is by far the most important source of non-carbon power generation in China in the year 2010. The only alternatives to coal that could provide significant amounts of energy for direct use before 2010 are coal-bed methane, biomass, natural gas, and possibly solar.

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[12] A "high-substitution" scenario is used in the *Summary Report* that is adapted from the three alternative energy scenarios in this report.

Table 3.2 Alternative Electric Power Scenarios, 2010

	Baseline Production (TWh)	Percent	AE-Max Scenario* (TWh)	Percent
Total	2,430	100%	2,430	100%
Coal	1,903	78%	1,627	67%
Hydro	360.0	15%	472.5	19%
Mini-Hydro	105.0	4%	157.5	6%
LNG	18.0	1%	90.0	4%
Nuclear	37.8	1.5%	60.0	2.5%
Solar PV Grid	0.2	0.0%	0.9	0.0%
Solar PV Non-Grid	0.9	0.0%	2.0	0.1%
Wind	1.5	0.1%	12.5	0.5%
Mini-Wind	0.2	0.0%	1.2	0.0%
Solar Thermal	0.8	0.0%	1.5	0.1%
Biogas	0.2	0.0%	1.0	0.0%
Geothermal	1.0	0.0%	2.5	0.1%

* Details of the three Alternative Energy (AE) scenarios (Min, Mid, Max) are provided in Annex 1. Note that AE-Max is different from the "high-substitution" scenario that is used in the *Summary Report.*

3.5 **Longer-term.** Alternative fuels, including hydro, nuclear, wind, and solar, could provide more than 40 percent of China's electricity by 2020, equivalent to between 15 and 20 percent of total energy. While there are a number of low-carbon substitutes for coal in electric power generation, such as hydro, nuclear, wind, and solar, currently more than 80 percent of the energy used in China is directly consumed for process heat or for residential cooking and heating. Even with accelerated growth in electric power sector in China, direct use of energy will still account for around 60 percent of total commercial energy in the year 2020. Direct substitution for coal by fuelwood is estimated to be able to provide 75 mtce by 2020, while coal-bed methane could provide up to 40 mtce of energy by 2020.

(1) Electric Power Alternatives

3.6 **Hydro.** Hydropower is part of China's least-cost development program for electric power generation and China is rapidly developing its hydroelectric resources. Under the baseline scenario, which assumes that 80 percent of China's hydro resources are developed by 2050, hydro capacity expands from 36 GW in 1990 to about 138 GW in the year 2020. Despite the large expansion in hydro capacity, hydro's contribution to power generation drops from 20 percent in 1990 to about 16 percent in 2020. Even assuming a development program in which China develops every economic hydro site by the middle of the 21st century, hydro's contribution to total electricity production would still fall below 20 percent by the year 2020. If hydro resources are developed at a faster pace than the baseline scenario, the key question is how rapidly the marginal cost of installed capacity will rise.

Table 3.3 Alternative Electric Power Scenarios, 2020

	Baseline Production (TWh)	Percent	AE-Max Scenario (TWh)	Percent
Total	3850	100.0%	3850	100.0%
Coal	2953	77%	2099	55%
Mini-Hydro	133.0	2.9%	192	5%
Wind	4.2	0.1%	18.2	0.5%
Geothermal	1.4	0.0%	3	0.1%
Hydro	486.0	10.7%	650	17%
Nuclear	208.4	4.6%	585	15%
Biogas	0.4	0.0%	2	0.1%
LNG	21.0	0.5%	97.5	2.5%
Solar PV	35.9	0.8%	182	5%
Mini-Wind	0.5	0.0%	1.9	0.1%
Solar Thermal	1.2	0.0%	4	0.1%

* Details of the three Alternative Energy (AE) scenarios (Min, Mid, Max) are provided in Annex 1. Note that AE-Max is different from the "high-substitution" scenario used in the *Summary Report*.

3.7 **Nuclear.** Most Chinese energy experts emphasize nuclear power development, together with hydro, as the principal alternatives to coal for electric power generation in China in the future. The baseline scenario assumes that China's nuclear capacity would grow from zero in 1990 to between 30 and 35 GW in 2020. The AE-Max scenario assumes that China would have nearly 100 GW of installed nuclear capacity by the year 2020. A slightly less ambitious nuclear scenario (the high substitution scenario) was used for the *Summary Report*. Under this scenario, China would have 87 GW of installed nuclear capacity by the year 2020, which would require China to complete more than ten 600 MW plants each year from 2010 onwards. Cost issues aside, such a nuclear program would be the largest in the world and would require immediate major action on technology development, personnel training, and the establishment of the necessary regulatory framework.

3.8 Nuclear power's expanded role in China depends on the development of low-cost reliable nuclear plants, and eventually either discovery of large uranium resources or radical change in the type of nuclear power plant now being built. Such advances will require significant investment in research and development in improved nuclear designs, which the current development plan for nuclear power in China appears unlikely to achieve.

Table 3.4: Nuclear Power Scenarios for China (GW)

Scenario	2000	2010	2050
Chinese Experts			
Low	3.3	7.3	120
Medium	4.3	8.3	180-240
High	5.3	10-20	360
International Expert Report*			
Low	2.1	2.4	12
Medium	2.1	3.3	20
High	2.1	4.5	50

*Desai (1992).

3.9 **Liquified natural gas.** The high capital costs and the lack of large numbers of suitable ports will limit the contribution of LNG in China's energy future. It is assumed that under the most optimistic case, China could develop four full-scale receiving facilities at 5,000 MW each by the year 2020. So far, little research and engineering has been done to determine how many feasible port facilities are available in China. Nor is it known how much the development costs of each potential site will be.

3.10 **Wind.** The wind energy resources that could be exploited in China in the stratum near the earth are more than 200,000 MW. The current capacity of wind generators in China is about 9 MW. Chinese energy experts estimate that wind generator capacity could increase at most to 4,300 MW by 2010 and 9,000 MW by the year 2020. For comparison, there is currently around 2,000 MW of wind-generated capacity worldwide. Nonetheless, 9 GW is a small fraction of the potential wind power in the country, and many international energy experts believe wind capacity could be expanded further. Finding good quality sites will not be a limiting factor in the near term development of the wind resource. However, areas where wind speeds are consistently high enough to justify wind farm development are mostly located in isolated regions of the country. Intermittent production requires that some form of back-up generation also be built. As mentioned above, increasing the quality and reducing the cost of turbine production is the only major barrier to making wind a significant component of China's electricity supply.

3.11 **Other renewables.** The joint study team estimates that as much as 82 GW of solar power generating capacity could be installed in China by the year 2020. In 1991, worldwide shipments of solar PVs were around 55 MW. Despite the potential for large-scale expansion of solar and wind, other renewables would only provide around 5 percent of electric power generation in 2020, and even this expansion will require significant reductions in technology costs. Massive investments in research and production will be needed to take advantage of the potential cost reductions resulting from mass production.

Table 3.5 Chinese Estimates of Biomass Usage (mtce)

	Direct Combustion	Large-scale gasification	Total Biomass Usage
Year 2000	236 million tce	30 million tce	266 million tce
Year 2010	214 million tce	50 million tce	264 million tce
Year 2020	110 million tce	160 million tce	270 million tce

(2) Non-power Alternatives

3.12 In addition to coal, China currently uses oil, natural gas, and biomass as direct fuel sources. It is expected that all additional sources of oil will be used in the transport and petrochemical sectors and are unlikely to be available for process loads or heating.

3.13 **Fuelwood.** The use of biomass fuels is expected to diminish in the future as commercial fuels become more available and as laws and regulations prohibit the exploitation of wood from public lands. Government and private efforts are underway in China to increase the supply of new biomass resources, particularly fuelwood from dedicated fuelwood plantations. While fuelwood plantations do not sequester much carbon on a net basis, their contribution to CO_2 reduction can be significant if fuelwood is substituted for fossil fuels. Fuelwood from new plantations could amount to 276 mt (air dry), or approximately 150 mtce, by 2020.

3.14 **Natural gas.** Natural gas sources may be expandable either by discovery and development of new domestic sources, including tapping the large reserves of coal-bed methane, or imported by way of pipeline construction or shipments of liquefied natural gas. It is assumed that in the future natural gas will be used primarily for residential and commercial energy purposes, and, depending on the total supply, could be used for electric power generation. Given the high value of natural gas in China, a more aggressive exploration and development program is warranted. Domestic natural gas production is assumed to rise from 15 bcm in 1990 to 115 bcm in 2020 under the baseline scenario and to 150 bcm under the most optimistic scenario. Both these scenarios will require large additions to proven natural gas reserves in China. Still, these amounts are equivalent to only 4 and 6 percent, respectively, of total projected energy use in China in the year 2020.

3.15 **Coal-bed methane.** Currently, only about 430 million cubic meters (cm) of methane, or less than 5 percent of methane emissions from large state-owned mines, is recovered through mine degasification and used. This amount could be increased to 2-4 billion cm if the state mines with methane recovery systems could increase their recovery to levels of best-practice in China. If coal production in China in the year 2020 expands to the levels envisioned by the baseline scenario, the amount of coal-bed methane that could be recovered and used with existing domestic technology would be about 30 bcm, or double the current natural gas production in China.

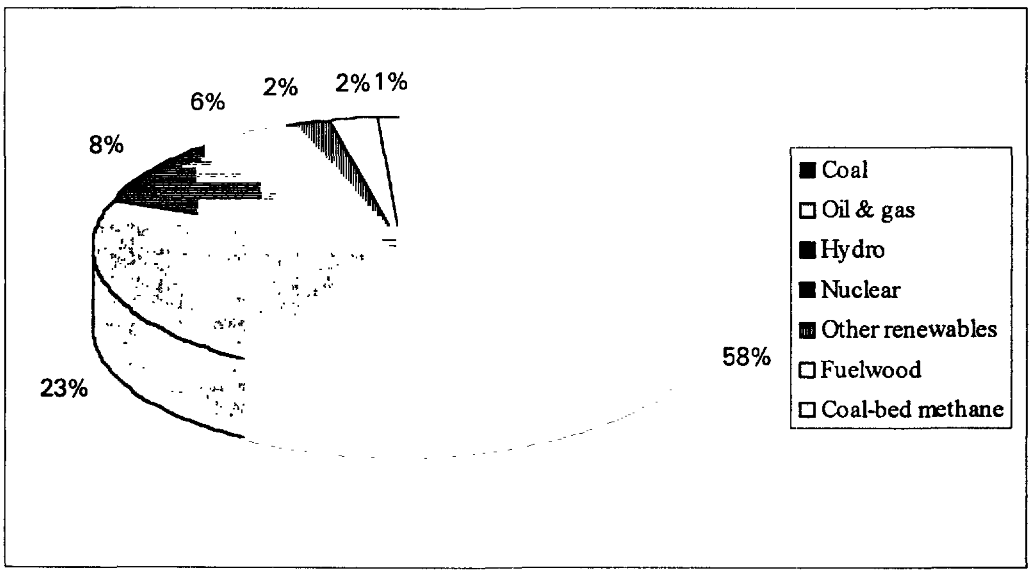
3.16 **Other renewables**. While small in comparison to overall energy use, other renewables can play an important role in specific applications. Solar for residential and industrial water heating, for example, has significant potential for displacing coal for direct use.

(3) GHG Reduction Potential

3.17 Under the baseline scenario, greenhouse gas emissions increase nearly three-fold between 1990 and 2020 from around 800 mtC to 2,400 mtC. Through the adoption of various mitigation measures, including the expansion of low-carbon energy technologies, it is estimated that China's GHG emissions could be limited to a two-fold increase between 1990 and 2020.

3.18 For estimating the GHG reduction potential in China, a "high (coal) substitution" scenario was created by the joint study team. The estimates of low-carbon energy supply used for the high substitution scenario are between the AE-Mid and AE-Max scenarios for electricity generation. In addition, estimates of low-carbon for direct substitution have been added. The overall results of the scenario for China's total energy supply in the year 2020 are shown in Figure 3.2.

Figure 3.2 Total Energy Supply in 2020, High Substitution Scenario



3.19 The potential for limiting GHG emissions through the expansion of low-carbon energy sources is presented in Table 3.6. Again, for GHG reduction from the electric power sector, the joint study team created a high substitution scenario based on the AE-Mid and AE-Max scenarios. Under the high substitution scenario, nearly 60 percent of the potential is in substitutes for coal for electric power generation. Of the low-carbon power potential, nuclear accounts for more than one-half, while additional hydro (above and beyond the baseline) accounts for around 19 percent. Non-power coal substitution comes from two dominant sources -- coal-bed methane and biomass production -- which together account for about 40 percent of the total GHG reduction potential from low-carbon energy technologies in the year 2020.

Table 3.6 Greenhouse Gas Reduction Potential for Low-carbon Energy Technologies, 2020

Low-carbon Technology	Reduction Potential: High Substitution Scenario (mtC)
Nuclear	74
Hydroelectric	26
LNG	6
Wind	5
Solar PV	28
Electricity-substitution	140
Coal-bed methane	42
Fuelwood (new plantations)	55
Direct use	97
TOTAL	**237**

B. The Cost of Expanding Alternative Energy Supplies

3.20 Based on a review of international and domestic experience, the joint study team has estimated the costs of expanding alternative energy sources. For electric power, where the number of alternative technologies are greatest, both investment and levelized generation costs have been estimated. Because major substitution before 2010 will be limited, the time frame for the cost estimates is roughly the year 2020. Ranges have been used to reflect the large degree of uncertainty for most of these estimates. Cost estimates for alternative energy sources that could substitute for coal or other fossil fuels for direct use have made use of the economic analyses conducted for this study and other GEF projects.[13]

3.21 Even under optimistic assumptions, most of the alternative energy sources that can be developed on a sizable scale in China over the next 25 years are more costly than coal.[14] Unless the costs of alternatives can fall to a level comparable with coal, there will be a large net cost for reducing CO_2 through the adoption of alternative energy. The joint study team estimates that, compared with the baseline scenario, it will require an additional 750 billion yuan (US$159 billion) to meet electric power demand in the year 2020 under the high substitution scenario.[15]

(1) Electric power

3.22 Under all alternative energy scenarios, the absolute amount of thermal power capacity in China will increase over the next 25 years. The extent to which low carbon-intensive fuels can be substituted for coal for power generation is related to upfront capital investment and capacity cost, and to the average cost of generating electricity for each of the alternatives.

Table 3.7 China: Estimates of Capital and Levelized Costs of Electric Power under Current Trends, 2020

	Investment Cost (1990 Y/KW)	Levelized Cost (1990 Y/KWh)	Average US$/KWh)
Coal	4,000-5,000	0.18-0.25	0.046
Wind (grid)	3,300-6,500	0.20-0.37	0.061
Geothermal	7,000-14,000	0.28-0.45	0.078
Incremental hydro	6,000-7,500	0.30-0.35	0.069
Nuclear	7,000-12,000	0.35-0.66	0.107
Biomass (gasified)	5,000-10,000	0.29-0.45	0.079
LNG	4,000-8,000	0.24-0.40	0.068
Solar PV	10,000-20,000	0.50-1.00	0.213
Solar thermal	8,000-12,000	0.32-0.70	0.109

[13] Cost estimates for coal-bed methane recovery and use were obtained from the Global Climate Change Division, US Environmental Protection Agency, which is involved in a GEF-supported technical assistance project assessing coal-bed methane use in China.

[14] The cost of coal use in China is assumed to increase, both for direct use and for electric power generation, due to more strict environmental controls on coal combustion.

[15] Cost estimates for the three alternative energy scenarios (AE-Min, AE-Mid, AE-Max) are provided in Annex 1. All cost estimates are in 1990 const nt prices and converted to US$ at the 1990 official exchange rate of 4.7 yuan/US$.

(2) Comparison of Levelized Costs

3.23 Coal is the cheapest and most expandable of all electricity-generation options. No other option can compare directly with coal in either levelized cost or ability to meet increased demand. Annex 1 shows the levelized costs of the various technologies as projected by Chinese and international experts. The key finding of the analysis is that the average cost of coal fired generation is likely to be considerably cheaper than other options for electricity generation in China. Table 3.8 shows the additional costs of expanding low-carbon energy technologies beyond the baseline in 2010 for several alternative energy scenarios. Therefore, in general, until costs of other technologies drop in China, there will be a positive cost to reducing CO_2 through the substitution of alternative energy technologies for coal. Support of these technologies will require incremental amounts of financial support if they are to actively be substituted. The exceptions are those technologies that are currently economic under certain conditions, including hydroelectric power, coal-bed methane, fuelwood production, domestic natural gas, and wind-powered electricity generation.

Table 3.8 The Costs of CO_2 Reduction, 2010

Year 2010	Baseline	AE-Min	AE-Mid	AE-Max
Electricity Consumed (TWh)	2,430	2,430	2,430	2,430
Total Investment (billion Yuan)	2,135	2,192	2,261	2,414
Levelized Cost (Yuan/KWh)	0.234	0.240	0.246	0.260
CO_2 Reduced (million tons over baseline)		16	36	59
Investment per CO_2 Reduced (Yuan/ton)		3,488	3,537	4,742
Levelized Cost per ton CO_2 Reduced		893	861	1,090

3.24 Electricity generation in China beyond 2010 is likely to continue to be dominated by coal unless major funds are provided to develop and promote alternatives. In addition, removing coal as a form of generation will be quite costly. As shown in Table 3.9, the levelized cost and investment required to accelerate low-carbon technologies beyond the baseline is considerable.

Table 3.9 The Costs of CO_2 Reduction, 2020

Year 2020	Baseline	AE-Min	AE-Mid	AE-Max
Electricity Consumed (tWh)	3,850	3,850	3,850	3,850
Total Investment (billion Yuan)	4,297	4,550	4,812	5,263
Levelized Cost (Yuan/kWh)	0.206	0.219	0.229	0.246
CO_2 Reduced (million tons over baseline)		48	96	179
Investment per CO_2 Reduced (Yuan/ton)		5,282	5,354	5,398
Levelized Cost per CO_2 Reduced		1,067	939	876

4. CONCLUSIONS AND RECOMMENDATIONS

A. Summary of Findings

4.1 By the year 2020, large-scale adoption of low-carbon energy sources could displace a substantial quantity of coal in China, particularly for electric power generation. Based on a projection of current trends in technological development, the joint study team estimates that low-carbon fuels could provide as much as 35-40 percent of electric power generation and 15-20 percent of China's total energy supply by the year 2020.

4.2 However, large-scale substitution of coal use by 2020 based on current alternative energy technologies can be achieved only at enormous financial cost. According to the analysis, most of the low-carbon fuels that could substitute on a large scale for coal will be more costly than coal over the next twenty-five years, even when an environmental premium is added to the cost of coal. Expanded development, beyond current trends, of nuclear power, hydro, wind, solar, gas and other non-coal energy sources is therefore very expensive. As an example, to reduce the share of coal in total energy use in the year 2020 from 65 percent (baseline scenario) to 58 percent would carry an additional cost of more than US$100 billion.

4.3 There are a number of existing alternative energy technologies that are currently cost-effective compared with coal under a wide variety of conditions. There is thus some opportunity for expanding low-cost "no-regrets" investments in low-carbon energy supply technologies, including investments in hydroelectric power, the use of coal-bed methane, fuelwood production under favorable natural conditions, expanded exploration and development of natural gas, and wind-powered electricity generation in certain places. However, significant development of alternative energy technologies can only occur in China by lowering investment and operating costs; this will require technology development.

B. Policy Recommendations

4.4 China is likely to require large quantities of alternative energy supplies during the early part of the next century for local environmental and logistical reasons, in addition to global environmental concerns. Given the abundance of low-cost coal resources in China, the necessary technological development of alternative energy sources is not likely to occur at sufficient speed solely through reliance on market forces. At present, China's energy industry is guided by short-term objectives focused on alleviating shortages and adjusting to the new market environment. Institutional responsibilities for developing alternative energy sources are also fragmented. However, large-scale development of coal alternatives in the future requires sustained policy support and strategically placed investment for technology development and demonstration today.

4.5 Accelerated development of alternative energy sources will require a program of well-targeted Government and international support for technology development, especially for renewable energy. The first step in this process is the adoption of a well-targeted and clear overall strategy for the development of cost-effective alternative energy technologies. A study has recently been completed in China by the three commissions responsible for alternative energy development policy,[16] which outlines a plan for alternative energy during the 9th five-year plan (1996-2000).

4.6 The joint study team recommends that the Chinese government establish, with international assistance where required, an aggressive program to accelerate the development of alternative energy sources, particularly renewable energy technologies. Primary emphasis should be given to technologies which ultimately have the potential to make a large contribution to China's long-term energy supply. The program should focus on research, technology transfer from abroad, and technology demonstration and dissemination activities aimed to reduce the costs of alternative energy supply and to improve cost-effectiveness compared with use of coal. Transfer of advanced technology from abroad clearly will be important in the proposed technology development effort. It should be recognized, however, that the developed countries do not face the same challenge that China faces to develop very large new supplies of non-coal energy for economic development. To spur technology development and lower costs, it is probably necessary for China to establish strong domestic research and development and manufacturing capabilities. For these reasons, technical leadership in China for the development of alternative energy technologies is needed.

4.7 Technical assistance and transfer and demonstration of approaches and techniques new to China can accelerate the development of alternative energy and should be promoted. One of the most important means of promoting the transfer of technologies to China is through policy reform to allow private sector investment. As described in Chapter 2, important advances have been made world-wide in the last few years in many alternative energy technologies. Liberalizing trade policies in China and in supplier countries could greatly aid in the transfer of commercial or near-commercial technologies. In addition to the private sector, bilateral and international assistance, including support from the GEF, can also be important in introducing new technologies and approaches to China.

4.8 Examples of alternative energy technologies that have been proven abroad and which could be transferred to China include expanded coal-bed methane extraction and use, and further development of sustainable biomass fuel use, such as through development of high-yield plantations for fuelwood production for direct use or for power

[16] The three national agencies are: the State Planning Commission, the State Science and Technology Commission, and the State Economic and Trade Commission.

generation. Other examples of technologies that have potential for cost-effective substitution of coal on a large scale in China, but which need further development, include more cost-effective methods for harnessing nuclear power, wind farms based on large-scale generators, advances in solar photovoltaic and thermal-electric technologies, large-scale biomass energy utilization schemes, and new methods for extracting natural gas under difficult geological conditions. Displacement of coal in non-power uses in China, such as industrial process heat and residential cooking, will be a particular challenge.

4.9 Based on the research carried out under the overall China greenhouse gas study, there are two major options for reducing greenhouse gas emissions in China: (i) improvements in energy efficiency, and (ii) the substitution of low- or non-carbon energy technologies for fossil fuels. Based on current cost-effectiveness, energy efficiency improvements can and should be undertaken immediately and be sustained. However, unlike energy efficiency, which only buys the world time in terms of lowering atmospheric concentrations of GHGs, low- or non-carbon technologies are the only sustainable option for limiting GHG emissions. While large-scale adoption of low-carbon energy supplies cannot be immediately undertaken in China, without action now on technology development, China will be unable to realize even modest increases in alternative energy supplies in the future.

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ANNEX 1.1 COST OF ALTERNATIVE TECHNOLOGIES FOR ELECTRICITY GENERATION IN 2000 BAU (IN 1990'S YUAN)

BUSINESS AS USUAL IN 2000	Unit	TOTAL	COAL	HYDRO	MINI-	IMPORTED-	NU-	SOLAR	SOLAR	WIND	MINI-	SOLAR	BIOGAS	GEO-
-ELEC. GENERATION					HYDRO	GAS-BASED	CLEAR	PV [1]	PV [2]		WIND	THERMAL		THERMAL
1. Electricity demand in 2000	TWh	1302.00	940.23	247.50	87.50	6.00	19.80	0	0.17	0.41	0.09	0.00	0.10	0.20
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	2200	2700	3100	2500	2000	5000
3. Capacity required in 2000	GW	290.23	188.05	65.13	32.41	1.00	3.30	0.00	0.08	0.15	0.03	0.00	0.05	0.04
4. Existing capacity in 1992	GW	165.74	125.00	24.00	16.00	0.40	0.30	0	0.00	0.00	0.00	0.00	0.01	0.03
5. New capacity required (3-4)	GW	124.49	63.05	41.13	16.41	0.60	3.00	0	0.08	0.15	0.03	0.00	0.04	0.01
6. Investment per kW	Yuan/kW		4500.00	5360	4500	3608	8500	28400	39400	7160	10000	13200	5000	7000
7. Total investment required	Billion yuan	749.11	319.11	298.19	83.05	2.16	41.86	0.03	3.05	1.04	0.30	0.00	0.22	0.09
8. Interest rate = 12%	% annual	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
9. Econon . life	Years		25.00	50.00	30.00	25.00	30.00	30.00	30.00	20.00	10.00	20.00	30.00	15.00
10. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
11. Annualized investment cost (7*10)	Billion yuan	92.99	40.69	35.91	10.31	0.28	5.20	0.00	0.38	0.14	0.05	0.00	0.03	0.01
12. Annual maintenance cost	Billion yuan		11.17	5.96	1.66	0.04	0.96	0.00	0.02	0.02	0.01	0.00	0.00	0.01
13. Annual labour cost	Billion yuan		3.19	1.19	0.33	0.01	0.17	0.00	0.02	0.01	0.00	0.00	0.00	0.00
14. Annual fuel cost	Billion yuan		9.24	0.00	0.00	0.79	1.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15. Total annual cost (11+12+13+14)	Billion yuan	129.11	64.28	43.06	12.30	1.12	7.65	0.00	0.42	0.16	0.06	0.00	0.03	0.02
16. Annual generation from new capacity	TWh	538.23	315.23	156.30	44.30	3.60	18.00	0.00	0.17	0.39	0.09	0.00	0.09	0.06
Ratio of total	%	100.00	58.57	29.04	8.23	0.67	3.34	0.00	0.03	0.07	0.02	0.00	0.02	0.01
17. Levelized cost (15/16)	Yuan/kWh	0.24	0.20	0.28	0.28	0.31	0.42	1.71	2.44	0.41	0.68	0.00	0.36	0.36
18. Period of construction	Years		3.00	6.00	3.00	1.00	9.00	1.00	1.00	1.00	1.00	3.00	1.00	3.00
19. Coal-equivalent coef. for elec.	g/kWh		350	350	350	350	350	350	350	350	350	350	350	350
20. Total elect. gen.(in coal equivalent)	Mtce	188.38	110.33	54.71	15.51	1.26	6.30	0.00	0.06	0.14	0.03	0.00	0.03	0.02
21. CO2 emission coef.	Ton carbon/tce	1.14	0.74			0.41								
22. Total CO2 emission	M.ton carbon	81.61	81.09			0.52								
23. Annual maintenance percentage	% annual	28.60	3.50	2.00	2.00	2.00	2.30	0.70	0.70	1.50	3.00	2.00	1.50	7.40
24. Contribution to peak load	GW	124.50	63.05	41.13	16.41	0.60	3.00	0.00	0.08	0.15	0.03	0.00	0.04	0.01
25. Additional coal-based capacity for	GW	13.04	0.00	0	12.31	0.60	0.00	0	0.00	0.13	0.00	0.00	0.00	0.00
meeting peak load demand														

ANNEX 1.2 COST OF ALTERNATIVE TECHNOLOGIES FOR ELECTRICITY GENERATION IN 2000 SCENARIO AE-MIN (IN 1990'S YUAN)

SCENARIOAE-MIN IN 2000	Unit	TOTAL	COAL	HYDRO	MINI-	IMPORTED-	NU-	SOLAR	SOLAR	WIND	MINI-	SOLAR	BIOGAS	GEO-
-ELECTRICITY GENERATION					HYDRO	GAS-BASED	CLEAR	PV [1]	PV [2]		WIND	THERMA L		THERMA L
1. Electricity demand in 2000	TWh	1302.00	926.13	247.50	87.50	12.00	25.80	0	0.21	2.16	0.12	0.13	0.20	0.25
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	2200	2700	3100	2500	2000	5000
3. Capacity required in 2000	GW	290.20	185.23	65.13	32.41	2.00	4.30	0.00	0.10	0.80	0.04	0.05	0.10	0.05
4. Existing capacity in 1992	GW	165.74	125.00	24.00	16.00	0.40	0.30	0	0.00	0.00	0.00	0.00	0.01	0.03
5. New capacity required (3-4)	GW	124.46	60.23	41.13	16.41	1.60	4.00	0	0.09	0.80	0.04	0.05	0.09	0.02
6. Investment per kW	Yuan/kW		4500	5360	4500	3608	8500	23800	34900	7160	10000	13200	5000	7000
7. Total investment required	Billion yuan	758.49	304.84	298	83	5.77	55.82	0.05	3.30	5.70	0.40	0.74	0.47	0.17
8. Interest rate = 12%	% annual	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
9. Economic life	Years		25	50	30	25	30	30	30	20	10	20	30	15
10. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
11. Annualized investment cost (7*10)	Billion yuan	94.18	38.87	35.91	10.31	0.74	6.93	0.01	0.41	0.76	0.07	0.10	0.06	0.03
12. Annual maintenance cost	Billion yuan		10.67	5.96	1.66	0.12	1.28	0.00	0.03	0.09	0.01	0.01	0.01	0.01
13. Annual labour cost	Billion yuan		3.05	1.19	0.33	0.02	0.22	0.00	0.02	0.03	0.00	0.00	0.00	0.00
14. Annual fuel cost	Billion yuan		8.82	0.00	0.00	2.11	1.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15. Total annual cost (11+12+13+14)	Billion yuan	131.61	61.41	43.06	12.30	2.99	10.20	0.01	0.46	0.88	0.08	0.12	0.07	0.04
16. Annual generation from new capacity	TWh	538.23	301.13	156.30	44.30	9.60	24.00	0.00	0.21	2.15	0.12	0.13	0.19	0.11
Ratio of substitution	%		100.00	0.00	0.00	-42.55	-42.55	-0.02	-0.27	-12.45	-0.22	-0.89	-0.71	-0.35
17. Levelized cost (15/16)	Yuan/kWh	0.24	0.20	0.28	0.28	0.31	0.42	1.43	2.21	0.41	0.68	0.94	0.36	0.36
18. Period of construction	Years		3.00	6.00	3.00	1.00	9.00	1.00	1.00	1.00	1.00	3.00	1.00	3.00
19. Coal-equivalent coef. for elec.	g/kWh		350	350	350	350	350	350	350	350	350	350	350	350
20. Total elect. gen.(in coal equivalent)	Mtce	188.38	105.39	54.71	15.51	3.36	8.40	0.00	0.07	0.75	0.04	0.04	0.07	0.04
21. CO2 emission coef.	Ton carbon/tce		0.74			0.41								
22. Total CO2 emission	M.ton carbon	78.84	77.46			1.37								
23. Annual maintenance percentage	% annual		3.50	2.00	2.00	2.00	2.30	0.70	1.00	1.50	3.00	2.00	1.50	7.40
24. Contribution to peak load	GW	116.52	69.83	31.00	9.00	1.60	4.00	0	0.09	0.80	0.04	0.05	0.09	0.02
25. Additional coal-based capacity for	GW	7.69	0.00	0.00	6.75	0.00	0.00	0.16	0.00	0.73	0.00	0.05	0.00	0.00
meeting peak load demand														

ANNEX 1.3 COST OF ALTERNATIVE TECHNOLOGIES FOR ELECTRICITY GENERATION IN 2000 SCENARIO AE-MID (IN 1990'S YUAN)

SCENARIO AE-MID IN 2000 -ELECTRICITY GENERATION	Unit	TOTAL	COAL	HYDRO	MINI-HYDRO	IMPORTED-GAS-BASED	NU-CLEAR	SOLAR PV [1]	SOLAR PV [2]	WIND	MINI-WIND	SOLAR THERMAL	BIOGAS	GEO-THERMAL
1. Electricity demand in 2000	TWh	1302.00	883.87	270.00	94.50	18.00	31.80	0.01	0.24	2.60	0.19	0.20	0.30	0.30
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	2200	2700	3100	2500	2000	5000
3. Capacity required in 2000	GW	292.55	176.77	71.05	35.00	3.00	5.30	0.00	0.11	0.96	0.06	0.08	0.15	0.06
4. Existing capacity in 1992	GW	165.74	125.00	24.00	16.00	0.40	0.30	0	0.00	0.00	0.00	0.00	0.01	0.03
5. New capacity required (3-4)	GW	126.81	51.77	47.05	19.00	2.60	5.00	0.00	0.11	0.96	0.06	0.08	0.14	0.03
6. Investment per kW	Yuan/kW		4500	5360	4500	3608	8500	21000	32200	7160	10000	13200	5000	7000
7. Total investment required	Billion yuan	791.58	262.06	341.11	96.17	9.38	69.77	0.06	3.40	6.86	0.60	1.19	0.72	0.25
8. Interest rate = 12%	% annual	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
9. Economic life	Years		25	50	30	25	30	30	30	20	10	20	30	15
10. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
11. Annualized investment cost (7*10)	Billion yuan	98.03	33.41	41.08	11.94	1.20	8.66	0.01	0.42	0.92	0.11	0.16	0.09	0.04
12. Annual maintenance cost	Billion yuan		9.17	6.82	1.92	0.19	1.60	0.00	0.03	0.10	0.02	0.02	0.01	0.02
13. Annual labour cost	Billion yuan		2.62	1.36	0.38	0.04	0.28	0.00	0.02	0.03	0.00	0.01	0.00	0.00
14. Annual fuel cost	Billion yuan		7.58	0.00	0.00	3.43	2.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15. Total annual cost (11+12+13+14)	Billion yuan	135.91	52.79	49.26	14.25	4.85	12.75	0.01	0.47	1.06	0.13	0.19	0.10	0.06
16. Annual generation from new capacity	TWh	538.23	258.87	178.80	51.30	15.60	30.00	0.01	0.23	2.59	0.19	0.20	0.29	0.16
Ratio of substitution	%		100.00	-39.93	-12.42	-21.29	-21.29	-0.01	-0.11	-3.90	-0.17	-0.35	-0.35	-0.18
17. Levelized cost (15/16)	Yuan/kWh	0.25	0.20	0.28	0.28	0.31	0.42	1.29	2.04	0.41	0.68	0.94	0.36	0.36
18. Period of construction	Years		3.00	6.00	3.00	1.00	9.00	1.00	1.00	1.00	1.00	3.00	1.00	3.00
19. Coal-equivalent coef. for elec.	g/kWh		350	350	350	350	350	350	350	350	350	350	350	350
20. Total elect. gen.(in coal equivalent)	Mtce	188.38	90.61	62.58	17.96	5.46	10.50	0.00	0.08	0.91	0.07	0.07	0.10	0.06
21. CO2 emission coef.	Ton carbon/tce		0.74			0.41								
22. Total CO2 emission	M.ton carbon	68.83	66.59			2.23								
23. Annual maintenance percentage	% annual		3.50	2.00	2.00	2.00	2.30	1.00	1.00	1.50	3.00	2.00	1.50	7.40
24. Contribution to peak load	GW	117.39	61.37	36.00	11.00	2.60	5.00	0.00	0.11	1.00	0.06	0.08	0.14	0.03
25. Additional coal-based capacity for meeting peak load demand	GW	9.25	0.00	0.00	8.25	0.00	0.00	0.00	0.00	0.92	0.00	0.08	0.00	0.00

ANNEX 1.4 COST OF ALTERNATIVE TECHNOLOGIES FOR ELECTRICITY GENERATION IN 2000 SCENARIO AE-MAX (IN 1990'S YUAN)

SCENARIO AE-MAX IN 2000	Unit	TOTAL	COAL	HYDRO	MINI-	IMPORTED-	NU-	SOLAR	SOLAR	WIND	MINI-	SOLAR	BIOGAS	GEO-
-ELECTRICITY GENERATION					HYDRO	GAS-BASED	CLEAR	PV [1]	PV [2]		WIND	THERMAL		THERMAL
1. Electricity demand in 2000	TWh	1302.00	832.04	292.50	105.00	30.00	37.80	0.01	0.25	3.00	0.25	0.25	0.50	0.40
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	2200	2700	3100	2500	2000	5000
3. Capacity required in 2000	GW	295.31	166.41	76.97	38.89	5.00	6.30	0.01	0.12	1.11	0.08	0.10	0.25	0.08
4. Existing capacity in 1992	GW	165.74	125.00	24.00	16.00	0.40	0.30	0	0.00	0.00	0.00	0.00	0.01	0.03
5. New capacity required (3-4)	GW	129.57	41.41	52.97	22.89	4.60	6.00	0.01	0.11	1.11	0.08	0.10	0.24	0.05
6. Investment per kW	Yuan/kW		4500	5360	4500	7900	8500	20000	31200	7160	10000	13200	5000	7000
7. Total investment required	Billion yuan	845.03	209.59	384.04	115.85	36.34	83.73	0.10	3.54	7.92	0.80	1.48	1.22	0.41
8. Interest rate = 12%	% annual	12	12	12	12	12	12	12	12	12	12	12	12	12
9. Economic life	Years		25	50	30	25	30	30	30	20	10	20	30	15
10. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
11. Annualized investment cost (7*10)	Billion yuan	104.44	26.72	46.24	14.38	4.63	10.39	0.01	0.44	1.06	0.14	0.20	0.15	0.06
12. Annual maintenance cost	Billion yuan		7.34	7.68	2.32	0.73	1.93	0.00	0.04	0.12	0.02	0.03	0.02	0.03
13. Annual labour cost	Billion yuan		2.10	1.54	0.46	0.15	0.33	0.00	0.02	0.04	0.00	0.01	0.01	0.00
14. Annual fuel cost	Billion yuan		6.07	0.00	0.00	6.07	2.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15. Total annual cost (11+12+13+14)	Billion yuan	144.12	42.22	55.46	17.16	11.58	15.30	0.01	0.49	1.22	0.17	0.24	0.18	0.09
16. Annual generation from new capacity	TWh	538.23	207.04	201.30	61.80	27.60	36.00	0.01	0.25	2.99	0.25	0.25	0.49	0.26
Ratio of substitution	%		100.00	-41.59	-16.18	-22.18	-16.64	-0.01	-0.07	-2.40	-0.14	-0.23	-0.37	-0.18
17. Levelized cost (15/16)	Yuan/kWh	0.27	0.20	0.28	0.28	0.42	0.42	1.23	1.97	0.41	0.68	0.94	0.36	0.36
18. Period of construction	Years		3.00	6.00	3.00	1.00	9.00	1.00	1.00	1.00	1.00	3.00	1.00	3.00
19. Coal-equivalent coef. for elec.	g/kWh		350	350	350	350	350	350	350	350	350	350	350	350
20. Total elect. gen.(in coal equivalent)	Mtce	188.38	72.46	70.46	21.63	9.66	12.60	0.00	0.09	1.05	0.09	0.09	0.17	0.09
21. CO2 emission coef.	Ton carbon/tce		0.74			0.41								
22. Total CO2 emission	M.ton carbon	57.21	53.26			3.95								
23. Annual maintenance percentage	% annual		3.50	2.00	2.00	2.00	2.30	1.00	1.00	1.50	3.00	2.00	1.50	7.40
24. Contribution to peak load	GW	118.40	51.01	41.00	14.00	4.60	6.00	0.01	0.11	1.20	0.08	0.10	0.24	0.05
25. Additional coal-based capacity for	GW	11.63	0.00	0.00	10.50	0.00	0.00	0.01	0.00	1.02	0.00	0.10	0.00	0.00

ANNEX 1.5 COST OF ALTERNATIVE TECHNOLOGY FOR ELECTRICITY GENERATION IN 2010 SCENARIO BAU (IN 1990'S YUAN)

BUSINESS AS USUAL	Unit	TOTAL	COAL-	HYDRO	MINI-	IMPORTED-	NU-	SOLAR	SOLAR	WIND	MINI-	SOLAR	BIOGAS	GEO-
IN 2010-ELEC. GENERATION			BASED		HYDRO	GAS-BASED	CLEAR	PV [1]	PV [2]		WIND	THERMAL		THERMAL
1. Electricity demand in 2010	TWh	2428.88	1903.30	360	105	18	37.8	0.22	0.88	1.5444	0.186	0.75	0.2	1
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	2200	2860	3100	2500	2000	5000
3. Capacity required in 2010	GW	525.29	380.66	94.74	38.89	3.00	6.30	0.10	0.40	0.54	0.06	0.30	0.10	0.20
4. Existing capacity in 1992	GW	165.74	125	24	16	0.4	0.3	0	0.0015	0.0045	0	0	0.006	0.028
5. New capacity required (3-4)	GW	359.55	255.66	70.74	22.89	2.60	6.00	0.10	0.40	0.54	0.06	0.30	0.09	0.17
6. Investment per kW	Yuan/kW		4500	6230	5000	3608	8500	19800	29340	6000	10000	10000	5000	7000
7. Total investment required	Billion yuan	2134.62	1294.05	596.05	128.73	9.38	83.73	1.98	11.69	3.21	0.60	3.37	0.47	1.35
8. Interest rate = 12%	% annual	12	12	12	12	12	12	12	12	12	12	12	12	12
9. Economic life	Years		25	50	30	25	30	30	30	20	10	20	30	15
10. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
11. Annualized investment cost (7*10)	Billion yuan	267.28	164.99	71.77	15.98	1.20	10.39	0.25	1.45	0.43	0.11	0.45	0.06	0.20
12. Annual maintenance cost	Billion yuan	511.54	45.29	11.92	2.57	0.19	1.93	0.02	0.12	0.05	0.02	0.07	0.01	0.10
13. Annual labour cost	Billion yuan		12.94	2.38	0.51	0.04	0.33	0.00	0.06	0.02	0.00	0.02	0.00	0.01
14. Annual fuel cost	Billion yuan		37.45	0.00	0.00	3.43	2.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15. Total annual cost (11+12+13+14)	Billion yuan	389.40758	260.68	86.08	19.07	4.85	15.30	0.27	1.63	0.49	0.13	0.54	0.07	0.31
16. Annual generation from new capacity	TWh	1665.11	1278.30	268.80	61.80	15.6	36.00	0.22	0.88	1.53	0.19	0.75	0.19	0.86
Ratio of toal	%	100.00	76.77	16.14	3.71	0.94	2.16	0.01	0.05	0.09	0.01	0.05	0.01	0.05
17. Levelized cost (15/16)	Yuan/kWh	0.23	0.20	0.32	0.31	0.31	0.42	1.22	1.86	0.32	0.68	0.71	0.36	0.36
18. Period of construction	Years		3	6	3	1	9	1	1	1	1	3	1	3
19. Coal-equivalent coef. for elec.	g/kWh		340	340	340	340	340	340	340	340	340	340	340	340
20. Total elect. gen.(in coal equivalent)	Mtce	566.14	434.62	91.39	21.01	5.30	12.24	0.07	0.30	0.52	0.06	0.26	0.06	0.29
21. CO2 emission coef.	Ton carbon/tce		0.735			0.409								
22. Total CO2 emission	M.ton carbon	321.62	319.45			2.17								
23. Annual maintenance percentage	% annual		3.5	2	2	2	2.3	1	1	1.5	3	2	1.5	7.4
24. Contribution to peak load	GW	278.74	198.48	56.00	14.00	2.60	6.00	0.10	0.40	0.54	0.06	0.30	0.09	0.17
25. Additional coal-based capacity for meeting peak load demand	GW	18.06	0.00	0	17.167		0	0.1	0	0.49	0	0.3	0	0

ANNEX 1.6 COST OF ALTERNATIVE TECHNOLOGY FOR ELECTRICITY GENERATION IN 2010 SCENARIO AE-MIN (IN 1990'S YUAN)

SCENARIO AE-MIN IN 2010 -ELEC. GENERATION	Unit	TOTAL	COAL	HYDRO	MINI-HYDRO	IMPORTED-GAS-BASED	NU-CLEAR	SOLAR PV [1]	SOLAR PV [2]	WIND	MINI-WIND	SOLAR THERMAL	BIOGAS	GEO-THERMAL
1. Electricity demand in 2010	TWh	2428.88	1824.3	382.5	122.5	42.0	43.8	0.4	1.4	8.6	0.6	1.0	0.4	1.5
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	2200	2860	3100	2500	2000	5000
3. Capacity required in 2010	GW	530.06	364.85	100.66	45.37	7.00	7.30	0.16	0.62	3.00	0.20	0.40	0.20	0.30
4. Existing capacity in 1992	GW	165.74	125	24	16	0.4	0.3	0	0.0015	0.0045	0	0	0.006	0.028
5. New capacity required (3-4)	GW	364.32	239.85	76.658	29.370	6.6	7	0.16	0.62	3.00	0.2	0.4	0.194	0.272
6. Investment per kW	Yuan/kW		4500	6230	5000	3608	8500	15100	24600	6000	10000	10000	5000	7000
7. Total investment required	Billion yuan	2191.87	1214.04	645.94	165.18	23.81	97.68	2.42	15.22	17.97	2.00	4.50	0.97	2.1
8. Interest rate = 12%	% annual	12	12	12	12	12	12	12	12	12	12	12	12	12
9. Economic life	Years		25	50	30	25	30	30	30	20	10	20	30	15
10. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
11. Annualized investment cost (7*10)	Billion yuan	274.23	154.79	77.78	20.51	3.04	12.13	0.30	1.89	2.41	0.35	0.60	0.12	0.31
12. Annual maintenance cost	Billion yuan		42.49	12.92	3.30	0.48	2.25	0.02	0.15	0.27	0.06	0.09	0.01	0.16
13. Annual labour cost	Billion yuan		12.14	2.58	0.66	0.10	0.39	0.00	0.08	0.09	0.01	0.02	0.00	0.02
14. Annual fuel cost	Billion yuan		35.14	0.00	0.00	8.71	3.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15. Total annual cost (11+12+13+14)	Billion yuan	399.46	244.56	93.28	24.47	12.32	17.84	0.33	2.12	2.77	0.42	0.71	0.14	0.49
16. Annual generation from new capacity	TWh	1665.1	1199.26	291.3	79.3	39.6	42	0.352	1.360	8.56	0.62	1	0.388	1.36
Ratio of substitution	%		100.00	-28.47	-22.14	-30.37	-7.59	-0.17	-0.61	-8.90	-0.55	-0.32	-0.25	-0.63
17. Levelized cost (15/16)	Yuan/kWh	0.24	0.20	0.32	0.31	0.31	0.42	0.93	1.56	0.32	0.68	0.71	0.36	0.36
18. Period of construction	Years		3	6	3	1	9	1	1	1	1	3	1	3
19. Coal-equivalent coef. for elec.	g/kWh		340	340	340	340	340	340	340	340	340	340	340	340
20. Total elect. gen.(in coal equivalent)	Mtce	566.14	407.75	99.04	26.96	13.46	14.28	0.12	0.46	2.91	0.21	0.34	0.13	0.4624
21. CO2 emission coef.	Ton carbon/tce		0.735			0.409								
22. Total CO2 emission	M.ton carbon	305.20	299.70			5.51								
23. Annual maintenance percentage	% annual		3.5	2	2	2	2.3	1	1	1.5	3	2	1.5	7.4
24. Contribution to peak load	GW	281.12	182.68	61	19	6.6	7	0.16	0.62	3.00	0.2	0.4	0.194	0.272
25. Additional coal-based capacity for meeting peak load demand	GW	25.34	0.00	0	22.03	0	0	0.16	0	2.76	0	0.4	0	0

ANNEX 1.7 COST OF ALTERNATIVE TECHNOLOGY FOR ELECTRICITY GENERATION IN 2010 SCENARIO AE-MID (IN 1990'S YUAN)

SCENARIO AE-MID IN 2010	Unit	TOTAL	COAL	HYDRO	MINI-	IMPORTED-	NU-	SOLAR	SOLAR	WIND	MINI-	SOLAR	BIOGAS	GEO-
-ELEC. GENERATION					HYDRO	GAS-BASED	CLEAR	PV [1]	PV [2]		WIND	THERMAL		THERMAL
1. Electricity demand in 2010	TWh	2428.88	1734.1	421.2	140	66	49.8	0.55	1.65	10.8	0.93	1.25	0.6	2
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	2200	2860	3100	2500	2000	5000
3. Capacity required in 2010	GW	535.09	346.82	110.84	51.85	11.00	8.30	0.25	0.75	3.78	0.30	0.50	0.30	0.40
4. Existing capacity in 1992	GW	165.74	125	24	16	0.4	0.3	0	0.0015	0.0045	0	0	0.01	0.03
5. New capacity required (3-4)	GW	369.35	221.82	86.84	35.85185	10.6	8	0.25	0.75	3.77	0.3	0.5	0.29	0.37
6. Investment per kW	Yuan/kW		4500	6230	5000	3608.00	8500	11700	21300	6000	10000	10000	5000	7000
7. Total investment required	Billion yuan	2260.55	1122.76	731.76	201.63	38.24	111.64	2.93	15.94	22.63	3.00	5.62	1.47	2.93
8. Inter . rate = 12%	% annual	12	12	12	12	12	12	12	12	12	12	12	12	12
9. Economic life	Years		25	50	30	25	30	30	30	20	10	20	30	15
10. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
11. Annualized investment cost (7*10)	Billion yuan	282.30	143.15	88.12	25.03	4.88	13.86	0.36	1.98	3.03	0.53	0.75	0.18	0.43
12. Annual maintenance cost	Billion yuan		39.30	14.64	4.03	0.76	2.57	0.03	0.16	0.34	0.09	0.11	0.02	0.22
13. Annual labour cost	Billion yuan		11.23	2.93	0.81	0.15	0.45	0.00	0.08	0.11	0.02	0.03	0.01	0.03
14. Annual fuel cost	Billion yuan		32.50	0.00	0.00	13.99	3.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15. Total annual cost (11+12+13+14)	Billion yuan	410.41	226.17	105.68	29.87	19.79	20.39	0.40	2.22	3.48	0.64	0.89	0.21	0.68
16. Annual generation from new capacity	TWh	1665.11	1109.1	330	96.8	63.6	48	0.55	1.6467	10.78	0.93	1.25	0.588	1.86
Ratio of substitution	%		100.00	-36.17	-20.69	-28.37	-7.09	-0.20	-0.46	-5.47	-0.44	-0.30	-0.24	-0.59
17. Levelized cost (15/16)	Yuan/kWh	0.25	0.20	0.32	0.31	0.31	0.42	0.72	1.35	0.32	0.68	0.71	0.36	0.36
18. Period of construction	Years		3	6	3	1	9	1	1	1	1	3	1	3
19. Coal-equivalent coef. for elec.	g/kWh		340	340	340	340	340	340	340	340	340	340	340	340
20. Total elect. gen.(in coal equivalent)	Mtce	566.14	377.09	112.20	32.91	21.62	16.32	0.19	0.56	3.67	0.32	0.43	0.20	0.6324
21. CO2 emission coef.	Ton carbon/tce		0.735			0.409								
22. Total CO2 emission	M.ton carbon	286.01	277.16			8.84								
23. Annual maintenance percentage	% annual		3.5	2	2	2	2.3	1	1	1.5	3	2	1.5	7.4
24. Contribution to peak load	GW	283.30	164.64	69.6	24	10.6	8	0.25	0.75	4.00	0.3	0.5	0.29	0.37
25. Additional coal-based capacity for meeting peak load demand	GW	31.11	0.00	0	26.88889	0	0	0.25	0	3.47	0	0.5	0	0

ANNEX 1.8 COST OF ALTERNATIVE TECHNOLOGY FOR ELECTRICITY GENERATION IN 2010 SCENARIO AE-MAX (IN 1990'S YUAN)

SCENARIO AE-MAX IN 2010	Unit	TOTAL	COAL	HYDRO	MINI-	IMPORTED	NU-	SOLAR	SOLAR	WIND	MINI-	SOLAR	BIOGAS	GEO-
-ELEC. GENERATION					HYDRO	GAS-BASED	CLEAR	PV [1]	PV [2]		WIND	THERMAL		THERMAL
1. Electricity demand in 2010	TWh	2428.88	1627.28	472.5	157.5	90	60	0.88	1.98	12.5	1.24	1.5	1	2.5
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	2200	2860	3100	2500	2000	5000
3. Capacity required in 2010	GW	540.80	325.46	124.34	58.33	15.00	10.00	0.40	0.90	4.37	0.40	0.60	0.50	0.50
4. Existing capacity in 1992	GW	165.74	125	24	16	0.4	0.3	0	0.0015	0.0045	0	0	0.01	0.03
5. New capacity required (3-4)	GW	375.062	200.456	100.34	42.333	14.6	9.7	0.4	0.90	4.37	0.4	0.6	0.49	0.47
6. Investment per kW	Yuan/kW		4500	6230	5000	7900	8500	10500	20000	6000	10000	10000	5000	7000
7. Total investment required	Billion yuan	2414.22	1014.63	845.51	238.08	115.34	135.36	4.20	17.97	26.20	4.00	6.75	2.47	3.72
8. Interest rate = 12%	% annual	12	12	12	12	12	12	12	12	12	12	12	12	12
9. Economic life	Years		25	50	30	25	30	30	30	20	10	20	30	15
10. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
11. Annualized investment cost (7*10)	Billion yuan	300.97	129.37	101.81	29.56	14.71	16.80	0.52	2.23	3.51	0.71	0.90	0.31	0.55
12. Annual maintenance cost	Billion yuan		35.51	16.91	4.76	2.31	3.11	0.04	0.18	0.39	0.12	0.13	0.04	0.28
13. Annual labour cost	Billion yuan		10.15	3.38	0.95	0.46	0.54	0.00	0.09	0.13	0.02	0.03	0.01	0.04
14. Annual fuel cost	Billion yuan		29.37	0.00	0.00	19.27	4.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15. Total annual cost (11+12+13+14)	Billion yuan	433.47	204.39	122.11	35.27	36.75	24.73	0.57	2.50	4.03	0.85	1.07	0.36	0.86
16. Annual generation from new capacity	TWh	1665.11	1002.28	381.3	114.3	87.6	58.2	0.88	1.9767	12.4871	1.24	1.5	0.988	2.36
Ratio of substitution	%		100.00	-40.76	-19.02	-26.09	-8.04	-0.24	-0.40	-3.97	-0.38	-0.27	-0.29	-0.54
17. Levelized cost (15/16)	Yuan/kWh	0.26	0.20	0.32	0.31	0.42	0.42	0.65	1.26	0.32	0.68	0.71	0.36	0.36
18. Period of construction	Years		3	6	3	1	9	1	1	1	1	3	1	3
19. Coal-equivalent coef. for elec.	g/kWh		340	340	340	340	340	340	340	340	340	340	340	340
20. Total elect. gen.(in coal equivalent)	Mtce	566.14	340.78	129.64	38.86	29.78	19.79	0.30	0.67	4.25	0.42	0.51	0.34	0.80
21. CO2 emission coef.	Ton carbon/tce		0.735			0.409								
22. Total CO2 emission	M.ton carbon	262.65	250.47			12.18								
23. Annual maintenance percentage	% annual		3.5	2	2	2	2.3	1	1	1.5	3	2	1.5	7.4
24. Contribution to peak load	GW	285.84	143.28	81	29	14.6	9.7	0.4	0.90	5.00	0.4	0.6	0.49	0.47
25. Additional coal-based capacity for meeting peak load demand	GW	36.770	0	0	31.75	0	0	0.4	0	4.02098	0	0.6	0	0

ANNEX 1.9 COST OF ALTERNATIVE TECHNOLOGY FOR ELECTRICITY GENERATION IN 2020 BAU (IN 1990'S YUAN)

BUSINESS AS USUAL IN 2020 ELECTRICITY GENERATION	Unit	TOTAL	COAL	HYDRO	MINI-HYDRO	IMPORTED GAS-BASED	NU-CLEAR	SOLAR PV	WIND	MINI-WIND	SOLAR THERMAL	BIOGAS	GEO-THERMAL
1. Electricity demand in 2020	TWh	3844.52	2952.57	486	133	21	208.35	35.915	4.2583	0.4595	1.1875	0.4	1.375
Ratio of total	%	100.00	76.80	12.64	3.46	0.55	5.42	0.93	0.11	0.01	0.03	0.01	0.04
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	3100	3200	2500	2000	5000
3. Capacity required in 2020	GW	824.69	590.51	127.89	49.26	3.50	34.73	16.33	1.37	0.14	0.48	0.20	0.28
4. Existing capacity in 1992	GW	165.74	86.40	24.00	16.00	0.40	0.30	0.00	0.00	0.00	0.00	0.01	0.03
5. New capacity required (3-4)	GW	658.95	504.11	103.89	33.26	3.10	34.43	16.33	1.37	0.14	0.48	0.19	0.25
6. Investment per kW	Yuan/kW		4500	7300	5500	7900	6500	6540	5500	8000	7600	5000	7000
7. Total investment required	Billion yuan	4297.40	2551.63	1025.80	205.76	24.49	367.36	106.77	7.55	1.11	4.06	0.95	1.93
8. Inter . rate = 12%	% annual	12	12	12	12	12	12	12	12	12	12	12	12
9. Economic life	Years		25	50	30	25	30	30	20	10	20	30	15
10. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
11. Annualized investment cost (5*8)	Billion yuan	538.53	325.33	123.52	25.54	3.12	45.61	13.25	1.01	0.20	0.54	0.12	0.28
12. Annual maintenance cost	Billion yuan	125.93	89.31	20.52	4.12	0.49	8.45	2.67	0.11	0.03	0.08	0.01	0.14
13. Annual labour cost	Billion yuan	32.20	26	4.10	0.82	0.10	1.47	0.11	0.04	0.01	0.02	0.00	0.02
14. Annual fuel cost	Billion yuan	93.62	74	0.00	0.00	4.62	15.15	0.00	0.00	0.00	0.00	0.00	0.00
15. Total annual cost (9+10+11+12)	Billion yuan	790.29	514.01	148.14	30.48	8.33	70.67	16.03	1.16	0.24	0.65	0.14	0.45
16. Levelized cost (13/1)	Yuan/kWh	0.21	0.17	0.30	0.23	0.40	0.34	0.45	0.27	0.51	0.54	0.34	0.32
17. Period of construction	Years		3	6	3	1	9	1	1	1	3	1	3
18. Coal-equivalent coef. for elec.	g/kWh		300	300	300	300	300	300	300	300	300	300	300
19. Total elect. gen.(in coal equivalent)	Mtce	1153.36	885.77	145.80	39.90	6.30	62.51	10.77	1.28	0.14	0.36	0.12	0.41
20. CO2 emission coef.	Ton carbon/tce		0.735			0.409							
21. Total CO2 emission	M.ton carbon	653.62	651.04			2.58							
22. Annual maintenance percentage	% annual		3.5	2	2	2	2.3	2.5	1.5	3	2	1.5	7.4
23. Contribution to peak load	GW	1015.26	564.86	192	62	5	120	65	4	0.4	1	0.5	0.5
24. Additional coal-based capacity for meeting peak load demand	GW	43.0068	0	0	24.944	0	0	16.325	1.265	0	0.475	0	0

ANNEX 1.10 COST OF ALTERNATIVE TECHNOLOGY FOR ELECTRICITY GENERATION IN 2020 SCENARIO AE-MIN (IN 1990'S YUAN)

SCENARIO AE-MIN IN 2020 -ELECTRICITY GENERATION	Unit	TOTAL	COAL	HYDRO	MINI-HYDRO	IMPORTED GAS-BASED	NU-CLEAR	SOLAR PV	WIND	MINI-WIND	SOLAR THERMAL	BIOGAS	GEO-THERMAL
1. Electricity demand in 2020	TWh	3844.52	2721.78	526.5	152.25	46.5	302.85	71.764	17.685	0.945	1.6875	0.8	1.75
Ratio of substitution	%	100.00	70.80	13.69	3.96	1.21	7.88	1.87	0.46	0.02	0.04	0.02	0.05
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	3100	3200	2500	2000	5000
3. Capacity required in 2020	GW	837.57	544.36	138.55	56.39	7.75	50.48	32.62	5.70	0.30	0.68	0.40	0.35
4. Existing capacity in 1992	GW	127.15	86.40	24.00	16.00	0.40	0.30	0.00	0.00	0.00	0.00	0.01	0.03
5. New capacity required (3-4)	GW	710.42	457.96	114.55	40.39	7.35	50.18	32.62	5.70	0.29	0.68	0.39	0.32
6. Investment per kW	Yuan/kW		4500	7300	5500	7900	6500	6540	5500	8000	7600	5000	7000
7. Total investment required	Billion yuan	4549.66	2318.00	1131.03	249.86	58.07	535.43	213.33	31.37	2.33	5.77	1.95	2.52
8. Interest rate = 12%	% annual	12	12	12	12	12	12	12	12	12	12	12	12
9. Economic life	Years		25	50	30	25	30	30	20	10	20	30	15
10. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
11. Annualized investment cost (5*8)	Billion yuan	569.11	295.54	136.20	31.02	7.40	66.47	26.48	4.20	0.41	0.77	0.24	0.37
12. Annual maintenance cost	Billion yuan		81.13	22.62	5.00	1.16	12.31	5.33	0.47	0.07	0.12	0.03	0.19
13. Annual labour cost	Billion yuan	31.52	23	4.52	1.00	0.23	2.14	0.21	0.16	0.01	0.03	0.01	0.03
14. Annual fuel cost	Billion yuan	112.19	80	0.00	0.00	10.23	22.21	0.00	0.00	0.00	0.00	0.00	0.00
15. Total annual cost (9+10+11+12)	Billion yuan	841.25	479.60	163.34	37.02	19.03	103.14	32.03	4.83	0.49	0.92	0.28	0.58
Ratio of substitution	%		100.00	-44.17	-18.99	-31 09	-94.36	-46.51	-10.65	-0.75	-0.79	-0.42	-0.40
16. Levelized cost (13/1)	Yuan/kWh	0.22	0.18	0.31	0.24	0.41	0.34	0.45	0.27	0.52	0.54	0.35	0.33
17. Period of construction	Years		3	6	3	1	9	1	1	1	3	1	3
18. Coal-equivalent coef. for elec.	g/kWh		300	300	300	300	300	300	300	300	300	300	300
19. Total elect. gen.(in coal equivalent)	Mtce	1153.356	816.536	157.95	45.675	13.95	90.855	21.5292	5.3055	0.2835	0.50625	0.24	0.525
20. CO2 emission coef.	Ton C/tce		0.735			0.409							
21. Total CO2 emission	M.ton carbon	605.86	600.15			5.71							
22. Annual maintenance percentage	% annual		3.5	2	2	2	2.3	2.5	1.5	3	2	1.5	7.4
23. Contribution to peak load	GW	1047.97	427.366	213	69	10	180	130	15	0.6	1.5	1	0.5
24. Additional coal-based capacity for meeting peak load demand	GW	80.835	0	0	42.2	0	0	32.62	5.24	0	0.675	0	0

ANNEX 1.11 COST OF ALTERNATIVE TECHNOLOGY FOR ELECTRICITY GENERATION IN 2020 SCENARIO AE-MID (IN 1990'S YUAN)

SCENARIO AE-MID IN 2020 -ELECTRICITY GENERATION	Unit	TOTAL	COAL	HYDRO	MINI-HYDRO	IMPORTED GAS-BASED	NU-CLEAR	SOLAR PV	WIND	MINI-WIND	SOLAR THERMAL	BIOGAS	GEO-THERMAL
1. Electricity demand in 2020	TWh	3844.52	2487.9	582.525	171.5	72	397.35	102.9125	22.6	1.4175	2.8125	1.2	2.25
Ratio of substitution	%	100.00	0.65	0.15	0.04	0.02	0.10	0.03	0.01	0.00	0.00	0.00	0.00
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	3100	3200	2500	2000	5000
3. Capacity required in 2020	GW	849.32	497.59	153.30	63.52	12.00	66.23	46.78	7.29	0.44	1.13	0.60	0.45
4. Existing capacity in 1992	GW	165.74	86.40	24.00	16.00	0.40	0.30	0.00	0.00	0.00	0.00	0.01	0.03
5. New capacity required (3-4)	GW	683.58	411.19	129.30	47.52	11.60	65.93	46.78	7.29	0.44	1.13	0.59	0.42
6. Investment per kW	Yuan/kW		4500	7300	5500	7900	6500	6540	5500	8000	7600	5000	7000
7. Total investment required	Billion yuan	4812.40	2081.28	1276.60	293.97	91.64	703.51	305.93	40.09	3.51	9.62	2.95	3.31
8. Interest rate = 12%	% annual	12	12	12	12	12	12	12	12	12	12	12	12
9. Economic life	Years		25	50	30	25	30	30	20	10	20	30	15
10. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
11. Annualized investment cost (5*8)	Billion yuan	600.71	265.36	153.72	36.49	11.68	87.34	37.98	5.37	0.62	1.29	0.37	0.49
12. Annual maintenance cost	Billion yuan	131.11	72.84	25.53	5.88	1.83	16.18	7.65	0.60	0.11	0.19	0.04	0.24
13. Annual labour cost	Billion yuan	30.90	21	5.11	1.18	0.37	2.81	0.31	0.20	0.02	0.05	0.01	0.03
14. Annual fuel cost	Billion yuan	117.88	73	0.00	0.00	15.84	29.14	0.00	0.00	0.00	0.00	0.00	0.00
15. Total annual cost (9+10+11+12)	Billion yuan	880.59	431.92	184.36	43.55	29.72	135.47	45.93	6.17	0.74	1.53	0.43	0.76
16. Levelized cost (13/1)	Yuan/kWh	0.23	0.17	0.32	0.25	0.41	0.34	0.45	0.27	0.52	0.54	0.35	0.34
17. Period of construction	Years		3	6	3	1	9	1	1	1	3	1	3
18. Coal-equivalent coef. for elec.	g/kWh		300	300	300	300	300	300	300	300	300	300	300
19. Total elect. gen.(in coal equivalent)	Mtce	1153.36	746.39	174.76	51.45	21.60	119.21	30.87	6.78	0.43	0.84	0.36	0.68
20. CO2 emission coef.	Ton carbon/tce		0.735			0.409							
21. Total CO2 emission	M.ton carbon	557.43	548.59			8.83							
22. Annual maintenance percentage	% annual		3.5	2	2	2	2.3	2.5	1.5	3	2	1.5	7.4
23. Contribution to peak load	GW	1082.224	288.224	237	76	15	240	200	20	0.9	3	1.5	0.6
24. Additional coal-based capacity for meeting peak load demand	GW	102.249395	0	0	47.638889	0	0	46.778409	6.7070968	0	1.125	0	0

ANNEX 1.12 COST OF ALTERNATIVE TECHNOLOGY FOR ELECTRICITY GENERATION IN 2020 SCENARIO AE-MAX (IN 1990'S YUAN)

SCENARIO AE-MAX IN 2020	Unit	TOTAL	COAL	HYDRO	MINI-	IMPORTED	NU-	SOLAR	WIND	MINI-	SOLAR	BIOGAS	GEO-
-ELECTRICITY GENERATION					HYDRO	GAS-BASED	CLEAR	PV		WIND	THERMAL		THERMAL
1. Electricity demand in 2020	TWh	3844.52	2099.22	650.25	192.5	97.5	585	182.16	26.875	1.89	4.25	2	2.875
Ratio of substitution	%	100.00	0.55	0.17	0.05	0.03	0.15	0.05	0.01	0.00	0.00	0.00	0.00
2. Annual operating hours	Hours/year		5000	3800	2700	6000	6000	2200	3100	3200	2500	2000	5000
3. Capacity required in 2020	GW	871.34	419.844	171.1	71.3	16.25	97.5	82.8	8.669	0.590625	1.7	1	0.575
4. Existing capacity in 1992	GW	165.74	86.40	24.00	16.00	0.40	0.30	0.00	0.00	0.00	0.00	0.01	0.03
5. New capacity required (3-4)	GW	705.60	333.44	147.12	55.30	15.85	97.20	82.80	8.67	0.59	1.70	0.99	0.55
4. Investment per kW	Yuan/kW		4500	7300	5500	7900	6500	6540	5500	8000	7600	5000	7000
5. Total investment required	Billion yuan	5262.53	1687.76	1452.57	342.09	125.22	1037.25	541.51	47.67	4.69	14.53	4.95	4.29
6. Interest rate = 12%	% annual	12	12	12	12	12	12	12	12	12	12	12	12
7. Economic life	Years		25	50	30	25	30	30	20	10	20	30	15
8. Capital Recovery Factor(CRF)	%		0.1275	0.1204	0.1241	0.1275	0.1241	0.1241	0.1339	0.1770	0.1339	0.1241	0.1468
9. Annualized investment cost (5*8)	Billion yuan	654.93	215.19	174.91	42.47	15.96	128.77	67.23	6.38	0.83	1.95	0.61	0.63
10. Annual maintenance cost	Billion yuan	136.40	59.07	29.05	6.84	2.50	23.86	13.54	0.72	0.14	0.29	0.07	0.32
11. Annual labour cost	Billion yuan	29.65	17	5.81	1.37	0.50	4.15	0.54	0.24	0.02	0.07	0.02	0.04
12. Annual fuel cost	Billion yuan	125.86	62	0.00	0.00	21.45	42.90	0.00	0.00	0.00	0.00	0.00	0.00
13. Total annual cost (9+10+11+12)	Billion yuan	946.84	352.65	209.78	50.68	40.42	199.67	81.30	7.34	0.99	2.31	0.71	0.99
14. Levelized cost (13/1)	Yuan/kWh	0.25	0.17	0.32	0.26	0.41	0.34	0.45	0.27	0.53	0.54	0.36	0.34
15. Period of construction	Years		3	6	3	1	9	1	1	1	3	1	3
16. Coal-equivalent coef. for elec.	g/kWh		300	300	300	300	300	300	300	300	300	300	300
17. Total elect. gen.(in coal equivalent)	Mtce	1153.36	629.77	195.08	57.75	29.25	175.50	54.65	8.06	0.57	1.28	0.60	0.86
18. CO2 emission coef.	Ton carbon/tce		0.735			0.409							
19. Total CO2 emission	M.ton carbon	474.84	462.88			11.96							
20. Annual maintenance percentage	% annual		3.5	2	2	2	2.3	2.5	1.5	3	2	1.5	7.4
21. Contribution to peak load	GW	1139.632	47.132	263	85	20	360	330	25	1.2	5	1.5	0.8
22. Additional coal-based capacity for meeting peak load demand	GW	145.94	0	0	53.47	0	0	82.8	7.97	0	1.7	0	0

ANNEX 1.13 COST OF ALTERNATIVE TECHNOLOGY FOR ELECTRICITY GENERATION IN 2020, CALIFORNIA ENERGY COMMISSION LOW COST SCENARIO (IN 1990'S YUAN)

IN 2020 ELECTRICITY GENERATION	Unit	TOTAL	COAL	HYDRO	MINI-HYDRO	IMPORTED GAS-BASED	NU-CLEAR	SOLAR PV	WIND	MINI-WIND	SOLAR THERMAL	BIOGAS	GEO-THERMAL
1. Electricity demand in 2020 BAU	TWh	3844.52	2952.66	486	133	21	208.35	35.915	3.76	1.4783	0.7645	0.8125	0.775
2. Levelized cost	Yuan/kwh	0.267	0.221	0.398	0.398	0.275	0.520	0.363	0.262	0.262	0.325	0.295	0.283
3. Total annual cost	Billion yuan	1028.14	652.54	193.43	52.93	5.78	108.34	13.04	0.99	0.39	0.25	0.24	0.22
4. Capacity required in 2020 BAU	GW	691.55	449.42	138.70	49.26	3.50	31.71	16.40	1.72	0.46	0.14	0.12	0.12
5. Existing capacity in 1992	GW	165.74	86.40	24.00	16.00	0.40	0.30	0.00	0.00	0.00	0.00	0.01	0.03
6. New capacity required (3-4)	GW	525.81	363.02	114.70	33.26	3.10	31.41	16.40	1.72	0.46	0.14	0.11	0.09
7. Operating hours	Hours		6570	3504	2700	6000	6570	2190	2190	3200	5519	6570	6570
8. Investment per kW	Yuan/kW		7700.00	11000.00	11000.00	4900.00	22600.00	5900.00	3800.00	3800.00	13400.00	5600.00	11733.55
9. Period of construction	Years		5	5	3	1	10	1	1	1	3	2	3
10. Discount rate	%		12	12	12	12	12	12	12	12	12	12	12
11. Total investment required	Billion Yuan	6936.04	3551.53	1603.06	411.51	15.19	1245.82	96.76	6.52	1.74	2.09	0.67	1.16
1. Electricity demand in 2020 AE-MIN	TWh	3844.52	2721.7885	526.5	152.25	46.5	302.85	71.764	17.685	0.945	1.6875	0.8	1.75
2. Amount of substitution			1122.7315	596.2315	443.9815	397.4815	94.6315	22.8675	5.1825	4.2375	2.55	1.75	0.00
Ratio of total	%	100.00	70.80	13.69	3.96	1.21	7.88	1.87	0.46	0.02	0.04	0.02	0.05
3. Total annual cost	Billion Yuan	1074.14	601.52	209.55	60.60	12.79	157.48	26.05	4.63	0.25	0.55	0.24	0.50
4. Capacity required in 2020 AE-MIN	GW	716.60	414.28	150.26	56.39	7.75	46.10	32.77	8.08	0.30	0.31	0.12	0.27
5. Existing capacity in 1992	GW	165.74	86.40	24.00	16.00	0.40	0.30	0.00	0.00	0.00	0.00	0.01	0.03
6. New capacity required (3-4)	GW	550.86	327.88	126.26	40.39	7.35	45.80	32.77	8.07	0.29	0.31	0.11	0.24
7. Total investment required	Billion Yuan	7557.85	3207.73	1764.60	499.72	36.02	1816.27	193.34	30.68	1.11	4.61	0.66	3.12
1. Electricity demand in 2020 AE-MID	TWh	3844.52	2487.9525	582.525	171.5	72	397.35	102.9125	22.6	1.4175	2.8125	1.2	2.25
2. Amount of substitution			1356.5675	774.0425	602.5425	530.5425	133.1925	30.28	7.68	6.2625	3.45	2.25	0.00
Ratio of total	%	100.00	64.71	15.15	4.46	1.87	10.34	2.68	0.59	0.04	0.07	0.03	0.06
3. Total annual cost	Billion Yuan	1121.92	549.84	231.84	68.26	19.80	206.62	37.36	5.92	0.37	0.91	0.35	0.64
4. Capacity required in 2020 AE-MID	GW	739.72	378.68	166.25	63.52	12.00	60.48	46.99	10.32	0.44	0.51	0.18	0.34
5. Existing capacity in 1992	GW	165.74	86.40	24.00	16.00	0.40	0.30	0.00	0.00	0.00	0.00	0.01	0.03
6. New capacity required (3-4)	GW	573.98	292.28	142.25	47.52	11.60	60.18	46.99	10.32	0.44	0.51	0.17	0.31
7. Total investment required	Billion Yuan	8210.05	2859.52	1988.06	587.94	56.84	2386.73	277.25	39.21	1.67	7.68	1.02	4.12
1. Electricity demand in 2020 AE-MAX	TWh	3844.52	2099.22	650.25	192.5	97.5	585	182.16	26.875	1.89	4.25	2	2.875
2. Amount of substitution			1745.3	1095.05	902.55	805.05	220.05	37.89	11.015	9.125	4.875	2.875	0.00
Ratio of total	%	100.00	54.60	16.91	5.01	2.54	15.22	4.74	0.70	0.05	0.11	0.05	0.07
3. Total annual cost	Billion Yuan	1206.80	463.93	258.80	76.62	26.81	304.20	66.12	7.04	0.50	1.38	0.59	0.81
4. Capacity required in 2020 AE-MAX	GW	779.23	319.52	185.57	71.30	16.25	89.04	83.18	12.27	0.59	0.77	0.30	0.44
5. Existing capacity in 1992	GW	165.74	86.40	24.00	16.00	0.40	0.30	0.00	0.00	0.00	0.00	0.01	0.03
6. New capacity required (3-4)	GW	613.49	233.12	161.57	55.30	15.85	88.74	83.18	12.27	0.59	0.77	0.29	0.41
7. Total investment required	Billion Yuan	10026.25	2280.66	2593.63	882.13	79.63	3531.38	490.75	46.63	2.24	11.61	1.81	5.78