CHINA ENERGY, ENVIRONMENT, AND CLIMATE STUDY:

BACKGROUND ISSUES PAPER

prepared for the World Resources Institute by

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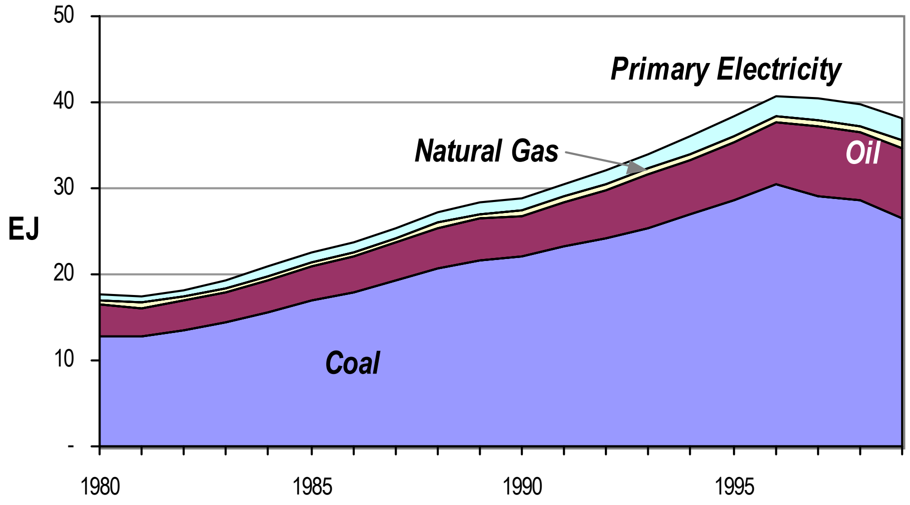
Introduction

The total costs and impacts of expanding energy use in China will depend, in part, on a number of important factors, an understanding of which is vital for China's policy-makers. These issues include the additional environmental and public health impacts associated with energy use, the economic costs of infrastructure expansion to meet growing energy needs, and the potential role that renewable energy technologies could play—if pushed hard—in China's energy future. This short report summarizes major trends and issues in each of these three areas.

I. The Environmental Impacts of Pollution Arising from Energy Production and Consumption

This section surveys the sources of pollutant emissions from energy use in China, identifies trends, and describes associated environmental and public health impacts. These encompass the direct health effects of air pollution, the impacts of acid deposition, and the potential effects of climate change, among other impacts. While energy use has fallen in China since 1996 (Figure 1), it is expected that consumption will begin to rise again soon, in line with expectations of long-term growth in China's economy, and that coal will continue to dominate the supply mix over the next few decades (Sinton and Fridley, forthcoming). The environmental damages from energy use are thus expected to become even more grave, unless further control measures are taken.

Figure 1. Primary Energy Use in China, 1980-1999



N.B. 1999 consumption estimated.

Source: Sinton and Fridley, 2000

A. ENERGY SUPPLY

Coal

Coal provides three quarters of China's commercial energy, and two thirds of all energy. It thus dominates the environmental impacts of the country's energy system. Every stage of the coal fuel cycle has serious effects.

As of the early 1990s, rates of mining deaths in China averaged over four per million metric tons (Mt) of coal mined, or about 5,000 per year (Sinton *et al*., 1996; Florig, 1997). This was an order of magnitude above rates in other countries with similar dependence on coal (Poland and India). In the U.S., where open-cast mines dominate production, there are fewer than 0.1 fatalities per Mt mined. Death rates in China's rural mines were about 40 percent higher than at large, state-owned mines (Sinton *et al*., 1996). Judging from news reports, accidents at China's coal mines have continued with frequencies similar to those in past years, suggesting that there were over 5,000 deaths in coal mining accidents in 1998. Statistics are not readily available for injuries due to accidents, or for mortality and morbidity from black lung disease and other occupational diseases.

Subsidence from coal mining affects at least 2,000 hectares of land each year, and disposal of mining waste takes another 1,000 hectares. Additional land is used for disposal of 70 Mt of coal ash each year (Sinton and Levine, 1995; EBCEY, 1997). Land reclamation required for mining, mainly of coal, is estimated to cost China from 100 to 200 million yuan per year (Smil, 1996).

Estimates are not available on the extent of damage from acid mine drainage, but one would expect that the problem would be widespread, given the existence of thousands of small and poorly maintained coal mines throughout the country. With the recent closure of up to 25,000 small coal mines, the risk of damage from this source will rise even further, as previous operators will have little incentive to maintain or clean up the closed mines.

Releases of coalbed methane are an important source of greenhouse gas emissions. Methane missions from coal mines were nearly 11 Mt in 1990, or about 29 percent of total anthropogenic methane emissions, the second largest source after rice paddies, with 33 percent (Joint Study Team, 1994, vol. 1).

Transportation impacts associated with coal use would include train accidents and land requirements for new rail lines and related facilities. In some cases, the effect is quite clear, as in the case of the dedicated rail line built to carry coal from Shanxi, in the northern interior, to Qinhuangdao, a port in Hebei, where coal is shipped to customers along the eastern and southern coasts.

There are also impacts associated with transformation of coal to coal gas and coke. Epidemiological studies have shown that the incidence of cancers is higher among residents in the vicinity of coal gas plants (Sinton, 1995). Similar impacts would be expected on the health of workers at and residents near China's many coking ovens, particularly those located in rural areas, which typically operate very inefficiently and have high emissions factors.

Electricity

Coal-fired Power

Among industrial sources of pollution in China, coal-fired power plants are the largest source of particulate and sulfur dioxide emissions, the second largest source of solid waste (and the largest source of coal ash), and the fourth largest source of wastewater (EBCEY, 1997). Because stack heights are generally high, pollutant emissions from power plants tend to have relatively less impact on human health than similar quantities of emissions from other sources (e.g., industrial boilers and household stoves). Power plants are of particular concern for their acid precursor and carbon dioxide emissions.

Existing fossil power stations place large demands on China's overused fresh water resources. Lack of water for cooling has been a major barrier in developing minemouth power plants in northern China, which has China's largest reserves of high-quality coal.

Coal-fired power stations consume an ever-growing portion of China's coal. Even as overall growth in coal use has shrunk after 1996, electricity consumption has continued to rise. Without improvements in efficiency, fuel quality, and combustion and emissions controls, electric utilities will place an increasingly heavy burden on the country's environmental capacity.

Hydropower

The environmental impacts of hydropower projects (mainly multipurpose dam projects) are far-reaching. They include: inundation of agricultural lands, settlements, wildlife habitat, and cultural and landscape resources; relocation of populations; impacts on biodiversity and fisheries; and seismic and other safety risks. On the other hand, the benefits of such projects—flood control, irrigation, transportation, fisheries, and recreation—can collectively be enormous. Hydropower is often advocated as an alternative to fossil fuel-fired power plants as to reduce greenhouse gas (GHG) emissions. In fact, hydropower does entail some CO_2 emissions from construction activities and significant methane emissions from decaying biomass in reservoirs (particularly in tropical and subtropical climates), although GHG emissions are far less than for fossil generation (Gagnon and van de Vate, 1997).[1]

Growth in installed capacity of hydropower projects has accelerated in the 1990s, as many large projects have come on line, while growth in coal-fired capacity has slowed (though it remains higher than that of hydropower; SSB, 1999). The outlook for hydropower remains strong, especially since the construction of the Three Gorges Project alone will add over 18 GW of new capacity, as it begins to come on-line in 2003. This and other projects will displace millions of people (who are typically moved to lands only marginally suitable for agriculture) and irreversibly destroy habitats.

In a slightly different vein, other sources of environmental degradation affect hydropower. Accumulation of silt, exacerbated by deforestation and agriculture, reportedly filled up one quarter of the reservoir capacity built between 1960 and 1989, with direct costs of 20 billion 1989 yuan (Li and Wang, 1989). Smil (1996) estimated the combined annual cost of lost power generation and of replacing hydropower capacity lost to siltation to be 1.4 to 1.8 billion yuan.

Nuclear Power

Issues of nuclear waste disposal, and plant decommissioning have received little attention in Chinese accounts of its civilian nuclear industry. Indeed, many basic data, e.g., regarding fuel use, spent fuel and wastes, are not available. Among the risks that have yet to be publicly discussed include:

- occupational and public health impacts of normal operation of nuclear fuel cycle, including decommissioning
- risk and consequences of catastrophic and less serious accidents; and
- security risks, e.g., diversion of fuel for use in terrorism or weapons production.

The lack of public discussion does not mean that China is unconcerned with such issues. As in other countries, for instance, China has plans and apparatus in place to track and respond to a variety of potential emergencies at nuclear power plants, and has developed equipment and standards for long-distance transport of nuclear materials.

While there are serious environmental and health consequences potentially associated with civilian nuclear power, there are environmental advantages as well. Nuclear power would generally replaces fossil-fuel power generation—mainly coal—and thus avoid emissions of carbon dioxide, sulfur dioxide, particulates, nitrogen oxides, heavy metals, and other emissions associated with burning fossil fuels.

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[1] The source calculated an emissions rate for a large dam in Brazil using extreme assumptions to arrive at a maximum emissions rate of 237 g CO_2 equivalent per kWh, several times smaller than emissions rates from fossil fuel-fired power plants.

Non-hydro Renewables

Non-hydro renewable energy sources include wind, solar photovoltaic, solar thermal, geothermal, biomass, and other technologies. While such energy forms do have life-cycle health and environmental impacts, ranging from occupational hazards of installing solar water heaters on the roofs of homes to occupation of land for wind farms and solar arrays, and emissions of toxic products of incomplete combustion from biomass. In general, the scale and nature of the environmental impacts associated with current renewable energy are less than those associated with the large-scale conventional energy technologies that now dominate energy supply. The consequences of unsustainable uses of biomass are discussed below.

Oil

Within China, concern about the environmental consequences of oil extraction, refining, storage and distribution focused on discharges to surface and ground waters (Sinton and Levine, 1995). Both point and area sources are present. Perhaps most important is the huge expansion of filling stations, tied to large-scale road building in the 1990s. In 1990, there were somewhat over 5,000 filling stations nationwide, and by 1998 there were over 90,000 (Sinopec, 1991; Reuters, 1999) As in other countries, it is likely that there will be widespread contamination from underground storage tanks at filling stations, although there are no figures available yet to quantify this.

Sulfur emissions from oil fields, terminals, and refineries have received some attention, but this is a secondary concern, as China's oil tends to have a low sulfur content (<0.1 percent). Growth in imports of oil and oil products with higher sulfur content, however, raises the importance of this issue (Sinton and Levine, 1995).

China's oil production has remained flat in recent years while consumption has continued to rise, prompting concerns among many in China. In the ten years up to 1998, oil use rose by an average of 5.5 percent per year, while production grew by 1.6 percent per year (CSICC, 1999; SSB, 1998 and 1999; BP Amoco, 1999). In that time, the country went from being a net exporter of oil and oil products, to a net importer, with foreign oil accounting for 16 percent of total supply, and expected to grow.[2]

If China's economic growth remains strong, and it continues to maintain a strong positive balance of trade, then the country will have little difficulty in paying for large increases in oil imports. On the other hand, dependence on imports may be perceived as an increased risk to China's national security. Some fear that this may lead China to increase expenditures on military forces that are perceived to be necessary to protect ocean shipping lanes and pipelines.

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[2] This figure rises to 18 percent if it is recalculated to include the approximately 5 Mt of oil products smuggled into China in 1998.

Natural Gas

While natural gas is the cleanest-burning fossil fuel and has the lowest level of carbon dioxide emissions, it is not without attendant environmental concerns. The magnitude of total impacts is now rather small, as gas contributes only 2 percent to the commercial fuel supply mix. At natural gas fields, hydrogen sulfide emissions are a concern, and will need to be controlled if gas output of China's onshore and offshore fields rises. Leaks from pipelines are a concern, not just for reasons of safety, but gas pipelines are a small but significant contributor of overall methane emissions. The most serious public safety concern would center around storage of compressed natural gas (CNG), which some coastal areas of China are considering importing for power generation and household use in densely populated areas.

Biomass

About half of all energy used in rural areas comes from biomass fuels, including wood, crop wastes, and grasses. This leads, in some areas, to unsustainable use and intense competition with other uses, such as fertilizer, animal feed, and protection of erosion and other ecosystem services. The overuse of crop wastes in biomass stoves can lead to loss of soil fertility, and higher demand for chemical fertilizers, which degrade the quality of soils with long-term overapplication, and contaminate agricultural runoff water. Widespread introduction of efficient biomass stoves has ameliorated the problem in many areas (Gu *et al*., 1991), and some uses of biomass, e.g., biogas digesters, even allow return to the soil of high-quality fertilizer. Perhaps even more significant has been the long-term trend to switch to coal (or gas fuels, where available), reducing biomass-related impacts but introducing new ones related to coal burning.[3]

Unsustainable harvesting of wood results in deforestation and degradation of China's remaining forest resources. Erosion from over harvesting of forests—in part for fuel—has contributed to increased frequency and destructiveness of flooding. Since 1949, the portion of the Yangtze River basin suffering from soil erosion has grown by 40 to 50 percent (Liu, 1998). Unsustainable use also removes an important sink for carbon dioxide emissions.

B. ENERGY USE

Pollutant emissions from energy use in China are high by any measure. Overall emissions of particulates, primarily from fuel combustion, have leveled off, or even fallen, as emissions controls have been implemented. Sulfur dioxide emissions, on the other hand, have basically followed coal consumption, since rates of coal washing have not changed appreciably and fuel-gas desulfurization equipment is still rare (Table 1). Still, available statistics imply that sulfur dioxide emissions per unit of coal burned have fallen quite rapidly in the mid-1990s—a result that requires closer

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[3] See section III.D for a discussion of biomass fuel use.

analysis. According to some sources, the quality of coal (heat, sulfur, and ash content) have been improving since the mid-1990s, as a buyers' market for coal has been established, and consumers are able to choose based on quality (Sinton and Fridley, forthcoming). This trend is likely to continue, especially with the closing of many smaller mines in 1999, which tend to produce lower-quality product. Implementation of recent of new air quality regulations, aimed at reducing acid precipitation and ambient sulfur dioxide levels by restricting production and use of high-sulfur coal and requiring new power plants to have sulfur scrubbers, is also likely to cause the rate of SO_2 emissions per ton of coal burned to continue declining. Since total coal use in China has been falling, and may continue to fall or rise only slightly over the next several years, it is possible that China's SO_2 emissions have already passed a peak, assuming that any long-term growth in coal use is offset by strengthened implementation of emissions control measures.

Table 1. Energy Use and Pollutant Emissions

Item	Unit	1990	1995	1996	1997	1998	Remarks
Coal Use							
total	Mt	1,055	1,377	1,454	1,388	1,364	includes transformation, e.g., utilities
industrial enterprises	Mt	811	1,176	1,239	-	-	includes transformation, e.g., utilities
SO2 Emissions							
total	Mt	-	23.70	*23.57*	23.46	20.90	In SEPA data, 1997 emissions were 22.66 Mt, figure here is SSB data; 1996 figure is estimated
industrial enterprises, county level & above	Mt	14.95	14.05	13.97	13.63	12.10	includes transformation, e.g., utilities
Unit SO2 Emissions							
overall	kg SO2/ t coal	-	17.21	16.21	16.90	15.32	estimated total SO2 / emissions total coal use
industrial enterprises	kg SO2/ t coal	18.44	11.95	11.28	-	-	industrial SO2 emissions / industrial coal use
Particulate Emissions							
from combustion	Mt	-	8.38	7.58	6.85	-	
from industrial processes	Mt	-	6.39	5.62	5.48	-	
total	Mt	13.24	14.77	13.20	12.33	-	

Mt = million metric tons

Source: SSB, 1998 and 1999; SEPA, *State of the Environment*, various years.

While particulates and sulfur dioxide are arguably the pollutants of most immediate concern to Chinese authorities, other pollutants arising from energy use are also considered important, such as nitrogen oxides, volatile organic compounds, ozone, benzo pyrenes and other products of incomplete combustion, heavy metals, carbon monoxide, and carbon dioxide.

1. Local Air Pollution

SOURCES

Ambient air pollution levels in China's cities are high, both by domestic and international standards. The main sources of urban air pollutants are direct uses of coal and, increasingly, vehicles. As more households switch from coal to gas and electricity, and as factories are forced to move outside of heavily populated urban centers, vehicles are overtaking coal-burning devices as the primary polluters. Locally, then, vehicles were contributing the largest share to ambient levels of carbon monoxide, hydrocarbons, and nitrogen oxides even in the late 1980s and early 1990s (World Bank, 1997, Chapter 6).

Industry is China's major energy consumer, taking about two-thirds of all primary energy, and is consequently the largest emitter of energy-related pollutants. As Table 2 shows, utility and industrial boilers each account for over one-third of sulfur dioxide emissions in the sulfur dioxide control regions, i.e., the legislatively mandated regions in which emissions controls are being instituted to ameliorate acid precipitation and direct damages to human health. These are therefore the most important targets for sulfur dioxide abatement.

Table 2. SO_2 Emissions Sources in China's SO_2-Control Regions, 1998

Source	Shares of Total Emissions
Utility boilers	35 percent
Industrial boilers	34 percent
Industrial kilns	11 percent
Household stoves	12 percent
Other	8 percent
Total	*100 percent*

Source: State Environmental Protection Agency, 1999b.

Aside from the impacts of products of combustion, as gasoline and diesel use rise, it is to be expected that health impacts from exposure to fuels and fuel additives will rise, other things being equal. Exposure to gasoline is associated with a variety of acute and chronic conditions, including liver cancer, leukemia, myeloma, heart disease, kidney disease, nervous system disorders, skin diseases, and alterations to mucous membranes (Caprino and Togna, 1998). On the other hand, China's refineries are in the process of reformulating gasoline, removing the alkyl leads that are potent neurotoxins, associated with acute damages to neurological development. It is likely that further reformulation, e.g., reducing the content of benzene, a potent carcinogen, will reduce the health risks (other than accidental burns) presented by gasoline use. This would tend to reduce the net impacts of rising fuel use.

Some clean-fuel vehicle programs have begun to appear in China. Beijing and Sichuan, for instance, are introducing fleets of LPG- and CNG-fueled vehicles and associated filling stations (ERM, 1999).

HEALTH IMPACTS

Air pollution has been definitively linked to a variety of human health problems, e.g., chronic and acute respiratory illnesses, lung cancers, and loss of lung function, although the mechanisms of causation often cannot be precisely determined. Elevated levels of airborne particulates and sulfur dioxide from fuel combustion have already been shown to cause increased morbidity and mortality in China (Xu *et al*., 1994). Unlike the case in developed countries, studies in Chinese cities appear to show that sulfur dioxide is more responsible for deaths from air pollution than are particulates (Cropper and Simon, 1995).[4]

According to Florig (1997), air pollution was responsible for one in every seven deaths in China in the early 1990s, over one million each year, mainly due to exposure to pollutants from indoor heating with biomass and coal. This rate is seven to ten times that in the US, adjusted for age. Florig also estimated annual mortality due to air pollution in rural and urban areas by disease type (Table 3). Dasgupta *et al.* (1997) estimated that about 4,000 people die annually from air pollution in both Chongqing and Beijing, and about 1,000 annually in both Shanghai and Shenyang.

Table 3. Mortality Due to Air Pollution

	Deaths per Year (thousands)	
Cause of Death	**Urban Areas**	**Rural Areas**
Chronic obstructive pulmonary disease	130-200	600-900
Lung cancer	14-20	40-80
Coronary heart disease	25-50	45-90
Childhood pneumonia	3-16	40-180
Deaths from all causes (including non-pollution-related illnesses and accidents)	2,200	5,700

Source: Florig, 1997.

A large portion of these deaths could be avoided simply through compliance with China's Class II standards for ambient air pollution, which are intended to protect human health and which apply to residential areas. As the World Bank (1997) estimated, nearly 300,000 deaths could be avoided annually by meeting these standards (Table 4).[5] In an earlier study, dose-response relationships were estimated for total suspended particulates and sulfur dioxide, relating them to mortality and morbidity, i.e., cases of physician visits, hospital admissions, adult respiratory symptoms, and adult restricted activity days (Joint Study Team, 1994, vol. 8). The mortality coefficients were calculated separately for two major cities, Beijing and Shanghai, which showed similar coefficients for total suspended particulates, but ones that differed by an order of magnitude for sulfur dioxide (Table 5). The morbidity coefficients were not separated out by city (Table 6).

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[4] Cropper and Simon (1997) found that mortality coefficients of air pollutant levels derived from studies in developed countries overestimated mortality rates, compared to coefficients they derived for Delhi, but that years of life lost were greater than expected in Delhi, because of the younger age of victims. These results may well apply to Chinese cities.

[5] These estimates are based on conservative assumptions about prevailing ambient and indoor air pollution levels. The impact of meeting air quality standards would vary depending on starting levels of air pollution in each locality.

As China continues to industrialize, such impacts are likely to worsen unless significant control measures are undertaken. One study that modeled emissions and transport of SO_2 from rising energy use in southern Jiangsu and Shanghai to 2010 found that, unless emissions were controlled, most areas would experience levels in excess of WHO's long-term guidelines for ambient SO_2 levels (Chang *et al*., 1998). This area of China already experiences the highest cancer rate in the country, and the increase in long-term ambient pollution levels would further increase the burden of pollution-related illness and death in the region. According to one set of estimates, illness and death from air pollution in 1990 cost China 3.8 to 6.5 billion yuan (Smil, 1996).

Table 4. Avoided Morbidity and Mortality from Meeting China's Class II Air Quality Standards

Problem	Impact	Annual Damages (thousands)
Urban Air Pollution—Mortality	Excess deaths	178
Urban Air Pollution—Morbidity	Respiratory hospital admissions, cases	346
	Emergency room visits, cases	6,779
	Restricted activity days, years	4,537
	Lower respiratory infection/child asthma, cases	661
	Asthma attacks, cases	75,107
	Chronic bronchitis, cases	1,762
	Respiratory symptoms, cases	5,270,175
Indoor Air Pollution—Mortality	Excess deaths	111
Indoor Air Pollution—Morbidity	Respiratory hospital admissions, cases	220
	Emergency room visits, cases	4,310
	Restricted activity days, years	2,885
	Lower respiratory infection/child asthma, cases	420
	Asthma attacks, cases	47,755
	Chronic bronchitis, cases	1,121
	Respiratory symptoms, cases	3,322,631

Source: World Bank, 1997, Chapter 2.

Table 5. Mortality Exposure-Response Coefficients for TSP and SO_2 Emissions Reductions

		Low	Central	High
TSP	Beijing	0	2.05×10^{-9}	5.75×10^{-9}
	Shenyang	0	1.92×10^{-9}	3.84×10^{-9}
SO_2	Beijing	9.40×10^{-9}	2.07×10^{-8}	3.07×10^{-9}
	Shenyang	1.92×10^{-9}	3.84×10^{-9}	7.67×10^{-9}

N.B. These coefficients are used as values for *a* where change in mortality = *a* x change in TSP or SO2 x population.

Low and high figures are 95% confidence levels.

Source: Joint Study Team, 1994, vol. 8.

Table 6. Morbidity Exposure-Response Coefficients for TSP and SO_2 Emissions Reductions

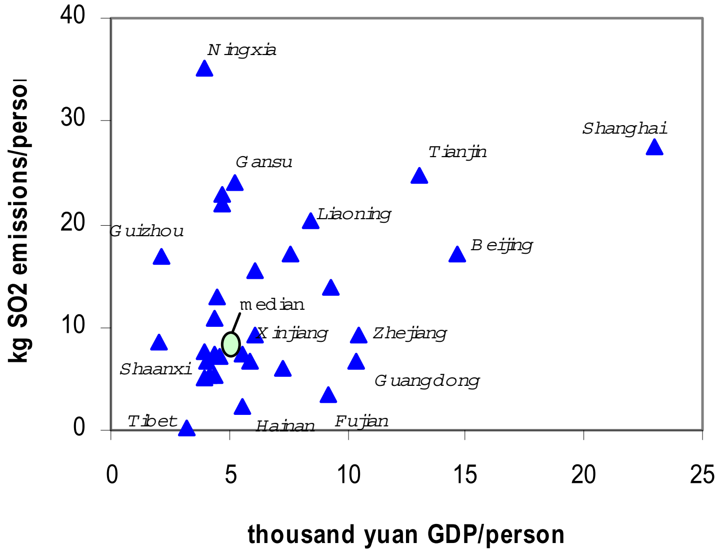
		Low	Central	High
TSP	Physician visits	1.39×10^{-7}	4.68×10^{-7}	7.40×10^{-7}
	Hospital admissions	1.24×10^{-8}	4.93×10^{-8}	9.95×10^{-8}
	Adult respiratory symptoms	9.90×10^{-2}	1.48×10^{-1}	2.20×10^{-1}
	Adult restricted activity days	2.22×10^{-2}	3.16×10^{-2}	4.97×10^{-2}
SO_2	Physician visits	8.36×10^{-7}	2.35×10^{-6}	3.86×10^{-6}
	Hospital admissions	0	1.49×10^{-7}	3.86×10^{-7}
	Adult respiratory symptoms	5.30×10^{-3}	1.02×10^{-2}	1.50×10^{-2}

N.B. These coefficients are used as values for *a* where change in morbidity = *a* x change in TSP or SO2 x population. Low and high figures are 95% confidence levels.

Source: Joint Study Team, 1994, vol. 8.

In many countries, people in poorer areas tend to bear a disproportion share of the total population exposure to pollutants. There is ample anecdotal evidence that, at least in some regions, industrial capacity is being shifted from urban areas to relatively poorer rural areas, particularly in the wealthier cities of the coastal provinces. The World Bank (1997) found a roughly negative correlation between ambient pollutant (TSP and SO_2) levels and average income in data on major cities in China. Data at the provincial level, however, do not exhibit a clear trend (Figure 2). Some provinces with low per capita incomes tend to exhibit higher than average per capita sulfur dioxide emissions (e.g. Ningxia and Gansu), while others are not very industrialized and have lower than average per capita emissions (Tibet and Shaanxi). Richer provinces may also have higher (Liaoning) or lower (Guangdong and Fujian) per capita emissions levels. China’s highest per capita GDP levels are in Shanghai, Tianjin, and Beijing, which are highly urbanized and industrialized, and thus have high per capita emissions levels.

Figure 2. Per Capita GDP and Sulfur Dioxide Emissions by Province



Source: Data from SSB, 1998.

Regional Air Pollution

Although ambient air pollution can be a regional problem as well as a local one, the primary issue of concern arising from energy use is acid precipitation. Emissions of acid precursors (sulfur dioxide and nitrogen oxides) lead to the formation of acid precipitation, including both dry and wet deposition, which causes damages of varying severity to forests, crops surface waters, and property. China is a major contributor to regional acid precipitation in Northeast Asia, as well as within its own borders (Streets *et al*., 1999). China has been monitoring domestic acid deposition and its effects under a State Environmental Protection Administration (SEPA)-administered program since the early 1980s. It has documented a variety of damages from wet and dry acid deposition, and found harm caused by pollutants transported over both short and long ranges (Wang and Wang, 1995). Once confined to the Southwest, affected regions now include areas north of the Yangtze River and in northern China, where alkaline soils have helped buffer acid deposition.

Sulfur dioxide is the most important acid precursor in China, and most emissions come from coal burning, the majority of which is used in power plants and factories. While most of China's coal is of good quality and low in sulfur, very little coal, other than the 20 percent or so used in metallurgy, is washed. Since sulfur emissions controls are almost unknown, outside of a few projects at power plants, even the burning of low-sulfur coal in China leads to very significant emissions (Table 2). Additionally, about one-fifth of the coal used in China's industrial and utility boilers is classified as high-sulfur coal, with over 1.5 percent sulfur (Qian and Zhang, 1998).

In 1995, SEPA reported that direct economic damages alone from acid precipitation in two of the most severely affected provinces, Sichuan and Guizhou, were 1.4 to 1.6 billion yuan (US$170 to 190 million) per year (China Environmental Yearbook, 1995). According to a study conducted by the Chinese Research Academy of Environmental Sciences, 40 percent of China is affected by acid rain causing US$1.6 billion worth of damage to crops, forests and property annually (Walsh, 1995). One estimate puts damages to forests alone at about US$1 billion per year (Smil, 1996). Total damages range in the tens of billions of yuan annually (Qian and Zhang, 1998). For comparison, in 1997 China spent 11.6 billion yuan (US$1.4 billion) on all pollutant discharge control programs, about one quarter of which was used for air pollution control (State Statistical Bureau, 1998).

Installing limestone injection equipment on all new power plants in China, thereby reducing SO_2 emissions from those plants by 50 percent, would require about US$4 billion per year, including operating and solid waste disposal costs (Streets, 1997). According to the same source, installing and operating flue-gas desulfurization equipment, with a 95 percent SO2-removal rate, at those same plants would require about US$6 billion per year.

Global Air Pollution

On the global scale, anthropogenic emissions of greenhouse gases, including CO_2, CH_4, N_2O, and ozone-depleting chemicals (ODCs) are currently of greatest concern. Global climate change will lead to a wide range of human health impacts, including changes in incidences of infectious disease, malnutrition and other effects of diminished food supply, and higher rates of accidental injuries and deaths (Kovats *et al.*, 1998). Kovats identifies impacts of climate change that would result in human health impacts, including:

- Changes in fresh water availability and quality;
- Sea-level rise;
- Increased frequency of extreme weather events; and
- Changes in air quality, e.g., accelerated formation of photochemical pollutants.

It is also expected that warming from climate change would lead to increased populations of disease vectors, such as mosquitoes, that could further spread diseases like malaria, dengue, and schistosomiasis that are already major killers in tropical regions. Given the range of uncertainty surrounding the extent of various climate change effects, it is difficult to quantify these impacts, but it is certain that substantial costs would be associated with changes in global climate.

Taking steps to improve energy efficiency and reduce energy-related air pollutant emissions, as China is now doing, would have the important side benefit of reducing the impacts of climate change on China. For instance, one recent study estimated the near-term health benefits associated with meeting Berlin Mandate targets for CO_2

emissions reductions, using changes in avoidable deaths due to airborne particulates as an indicator (Working Group on Public Health and Fossil-Fuel Combustion, 1997).[6] The study estimated that implementing measures that would reduce CO_2 emissions could prevent up to 8 million premature deaths worldwide between 2000 and 2020, mainly in developing countries.

Wang and Smith (1998) developed a method for assessing the near-term health benefits associated with reductions in greenhouse gas emissions and applied it to China. The effects of reducing emissions by 10 percent in 2010 and by 15 percent in 2020 compared to a business-as-usual were estimated under several scenarios, differing in the sources (sectors) of emissions reductions. The study concluded that substantial health benefits would result from efforts that, among other things, controlled greenhouse gas emissions, and that the nature and magnitude of those benefits would depend heavily on technology choice and the sectors in which the measures were taken. The health benefits of reducing one unit of particulate emissions from the household sector, for instance, would be 40 times those of lowering power plant emissions by one unit. Compared to projected total mortality for 2020, scenarios showed that 1 percent to 4 percent of deaths could be avoided (and morbidity could be reduced by a similar amount) as a result of GHG emissions reductions. The study also showed that including health benefits in economic analysis resulted in a net benefit for measures in the household sector that substituted other energy sources for coal and biomass.

Indoor Air Pollution

Indoor air pollution is one of China's worst environmental problems. Levels of particulates, sulfur dioxide, carbon monoxide, and carcinogenic compounds are high in the many urban and rural households that burn solid fuels directly for cooking and heating. Studies of indoor air pollution in common household settings suggest that a large portion of China's population is regularly exposed to levels of pollutants an order of magnitude higher than any domestic or international standard (Sinton, *et al.*, 1995). Continued widespread and inefficient use of biomass fuels and unprocessed coal in poorly ventilated rural households contributes to the continued dominance of respiratory illness as the leading cause of death in China's countryside. The problem remains serious in cities, but urban residences are increasing switching to gas and electricity for cooking and water heating, in part as the housing stock becomes dominated by apartment buildings rather than traditional one- and two-story homes. Fuel switching does not eliminate pollutants, but does change the focus away from particulates and sulfur dioxide to carbon monoxide and nitrogen oxides.

The magnitude of the health problem from indoor fuel use is roughly comparable to that posed by smoking, rates of which are very high for men in China. Women and

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[6] This assumes that developed countries reduce CO_2 emissions to 15 percent below 1990 levels by 2010. Developing countries are assumed to reduce emissions to 10 percent below emissions projected for 2010 under a "business as usual" scenario.

children are the main sufferers of disease induced by indoor air pollution, however, while the direct impacts of smoking fall mainly on men. Still, about 40 percent of lung cancers in males, and three quarters in women are attributable to indoor air pollution (Florig, 1997).

The problem has both chronic and acute dimensions. The main impact is through increased incidence of respiratory diseases. Every year, however, there are deaths from carbon monoxide poisoning, mainly in northern China, where coal is used to heat brick beds in tightly weatherproofed buildings. The increasing use of appliances such as water heaters fueled by town-gas has led to mortality and morbidity from that source as well.

Improved health is one of the most important benefits of switching fuels (e.g., from biomass or coal to gas or electricity) and technologies (e.g., from heating stoves to hot water central heating) to improve the efficiency and pollution characteristics of indoor energy uses. The magnitude of the improvement is indicated in Table 4, which suggests that 100,000 or more excess deaths per year could be avoided if indoor air in all China's buildings met the country's Class II air quality standards.

Water and Soil Impacts

Typically, the water and soil impacts of energy use are of a lesser magnitude than those from water pollution and solid waste from industry, households, and agriculture. Some of the issues of concern are: disposal of coal ash from power plants; thermal pollution from power plants; and release of oil products and additives (Pb, MTBE) from end users.

C. ECONOMIC VALUATION OF ENVIRONMENTAL IMPACTS

Valuation of environmental impacts is a difficult exercise, fraught with uncertainty. Not only are damages difficult to express in monetary terms, the comparison, GDP, is widely recognized to be an inadequate measure of national wealth and well being. Nevertheless, it is useful to be able to compare the approximate magnitude of the disbenefits of energy use with the economic benefits, as reflected in GDP. While most studies carried out to date have been in the US and other developed countries, many have been carried out in China and other developing nations, both domestically and with international participation.

Estimates of overall environmental damages, including pollution damages and environmental degradation, range from 5 percent to 15 percent of GDP (Table 7). The World Bank (1997) arrived at an estimate of 8 percent of GDP for damages from air and water pollution, calling that figure conservative. For comparison, calculations in an exercise performed for India——resulted in an estimate of nearly 5 percent of GDP in 1992 (Brandon, 1995). Since this figure left out a variety of significant impacts, such as damages from surface and groundwater pollution and health impacts of hazardous wastes, this must be considered a minimum value.

Smil (1996) put together a preliminary estimate of the values of a variety of pollution impacts. Those related to energy supply and use are in
Table 8. The largest single category of costs associated with air pollution is human health impacts, which is dominated by morbidity, as was found by the World Bank (1997). Estimates were not attempted for many categories of impacts, some of which could rival human health impacts if properly quantified. Smil identified these as photochemical smog, human suffering and discomfort, impacts from short-lived radioactive wastes, and climate change impacts.

In many cases, the cost of controlling energy-related emissions is outweighed by the health and environmental benefits of emissions reductions. In a major study of greenhouse gas emissions and mitigation options, case studies of energy efficiency investment projects in industrial sectors in China has shown that there is a significant reserve of projects that have positive net economic benefits associated with the resulting reductions of CO_2, SO_2, and particulate emissions —that is, true “no regrets” investment projects (Joint Study Team, 1994, vol. 3; London *et al.*, 1998). The study estimated that the economic costs of mortality and morbidity for emissions of particulates and sulfur dioxide were 165 yuan/ton and 530 yuan/ton respectively (at 1990 prices; Joint Study Team, 1994, vol. 8).[7]

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[7] Converting this to 1995 prices and using 1995 exchange rates for comparability with Table 9, the economic costs of mortality and morbidity for emissions of particulates and sulfur dioxide were US$35/ton and US$112/ton respectively. This latter figure is within the range of other estimates in Table 9. The authors of the study noted that the results were preliminary estimates. For example, including other impacts from emissions, e.g., acid precipitation damages, pain and suffering, and aesthetic impacts, would have increased these values, and raised the net benefits of the efficiency investments even higher.

Table 7. Estimates of Economic Value of Environmental Damages

Scope of Estimate	Total Amount	Percent of GDP	Year	Remarks	Source
Overall Damages					
Ecological destruction and environmental pollution		Up to 14 percent			Chen, 1997
Air and water pollution costs	US$54 billion/yr	Nearly 8 percent		Willingness to pay estimates. Hedonic cost approach yields a value of 3.5 percent.	World Bank, 1997
All environmental damages		10 percent (5 to 15 percent)	1990	High estimate includes order-of-magnitude estimates of unquantified impacts.	Smil, 1996
Air Pollution Damages					
All air pollution damages	11 to 19.2 billion yuan/yr	0.6 percent to 1.1 percent	1990	See Table 8 below.	Smil, 1996
All air pollution damages	50 billion yuan/yr	1.9 percent	1992	Alternate estimate quoted in same source, using higher estimate of health costs	
Morbidity and mortality costs	US$61 billion	11 percent	1990	Adjustments to original figures made in Pearce, 1997.	Florig, 1993
Acid Precipitation					
damage to forests, crops, and property	US$1.6 billion/yr			Chinese Research Academy of Environmental Sciences	Walsh, 1995
damage to forests	US$1 billion/yr				Smil, 1996

N.B. Damage estimates include damages due to pollution from all sources. In the case of certain damages, such as acid precipitation, virtually all pollutant emissions are the result of fossil fuel combustion, and can be attributed to energy use.

Table 8. Estimated Costs of Energy-Related Environmental Pollution and Damages in China, 1990

Category	Minimum (million yuan)	Maximum (million yuan)
Air Pollution	11,000	19,200
Human health	3,800	6,500
Respiratory morbidity	2,500	4,500
Respiratory mortality	500	800
Lung cancer mortality	500	800
Cardiovascular mortality	300	400
Damage to crops	2,100	4,300
Damage to forests	800	1,700
Damage to materials	2,000	4,000
Household cleaning	2,300	2,700
Land reclamation after mining	100	200
Photochemical smog	Not estimated (1-10 billion yuan)	
Short-lived radioactive wastes	Not estimated (0.01-1 billion yuan)	
Short-lived radioactive wastes	Not estimated (1->10 billion yuan)	
Human suffering and discomfort	Not estimated (1->10 billion yuan)	
Reduced visibility	Not estimated (0.1-1 billion yuan)	
Greenhouse gas emissions	Not estimated (1->10 billion yuan)	

Source: Smil, 1996.

Using figures on total emissions of sulfur dioxide and estimates of health and environmental damages proceeding from those emissions, it is possible to arrive at crude estimates of average unit damages per ton of sulfur dioxide emitted (Table 9). This gives a range of US$68 to $559 (1995) per ton of sulfur dioxide. Applying the same procedure to coal, we find that the average ton of coal results in US$1 to nearly $10 in damages from sulfur dioxide alone, to say nothing of damages from particulates, nitrogen oxides, heavy metals, and other pollutants. These figures can be used as a rough comparison when gauging the adequacy of fees imposed on burning of coal and emissions of sulfur dioxide.

Table 9. Unit Damages from Energy Use and Sulfur Dioxide Emissions

Total damages (million US$)	Damages per ton SO_2 emitted (US$/t SO_2)	Damages per ton coal used (US$/t coal)	Source of damage estimate	Remarks
$1,600	$68	$1.16	Walsh, 1995; Xinhua, 1998	based on study by Chinese Research Academy of Environmental Sciences
$4,300	$181	$3.12	The World Bank, 1997	extrapolated from Chongqing study
$11,800	$498	$8.57	China Daily, 1998	12 southern provinces only
$13,250	$559	$9.62	Sinanet, 1999a	combined damages from SO2 and acid precipitation

N.B. Since many damage estimates are for 1995, we have chosen to use the 1995 national totals of 23.7 Mt of SO2 emitted and of 1,377 Mt of coal used in all calculations of unit damages.

For incremental damages, it may be safe to assume a linear relationship between emissions and damages based on the unit damages per ton of sulfur dioxide found in the various studies. If changes in emissions are large, however, damages may change nonlinearly, e.g., total damages would fall off dramatically if emissions were reduced to the point where natural buffering capacity could sustainably neutralize acid precursors.

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II. Cost of New Energy Infrastructure

This section estimates the cost of building the energy infrastructure required to meet future energy demand defined in the China Country Study.[8] A baseline, policy, and low-policy scenario of infrastructure costs are included to mirror the structure of the Study. The analysis focuses on the major sectors of China's energy infrastructure such as coal production, coal transport, oil and gas exploration, oil and gas transport, and power plant construction. Other sectors and subsectors—such as petrochemical refining and power transmission—will also require capital investment, but the magnitude of spending in these sectors will likely be far less than the main areas defined above. The goal here is to demonstrate that a combination of policy mechanisms enacted by the central government can result in dramatically reduced infrastructure investment costs for the country's energy system. Clearly, this is only a partial analysis as the full costs and effects of instituting the policies would need to be considered. A general equilibrium model might do a better job of estimating these impacts. However, it is likely that the costs (i.e., developing renewable energy technologies) and benefits (reducing pollution damages) of enacting the policies would offset one another to some degree.

Energy demand growth has slowed since late 1997, and, as a result, it is unlikely that China will need as much energy in the near term as predicted by the *China Climate Change Country Study*. (See Table 8.) According to the baseline scenario in the *China Climate Change Country Study*, annual coal demand will reach 1,169 Mtce in 2000, and 2,347 Mtce in 2030 (1,637 and 3,286 million tons of *raw* coal, respectively[9]). Taking into account the recent development trends in China, researchers at the Energy Research Institute believe raw coal demand of 2,200 million tons in 2030 seems more reasonable as a baseline scenario.

Despite the slowdown in energy use, this section provides an insightful look at the relative investment costs required under three different growth scenarios. As the Chinese economy continues to evolve from centrally-planned to market orientation, infrastructure investments may come increasingly from commercial banks, the private sector, provincial and local governments, and other players. Likewise, financing for these infrastructure projects will likely reduce pressure on the central government to provide the huge amounts of capital to make the projects possible. An increasing proportion of costs will probably be recovered efficiently through energy pricing mechanisms.

Table 8 – Coal demand (million tons)

	1990	2000	2010	2030
Baseline	1,055	1,637	2,264	3,286
Policy scenario	1,055	1,479	1,850	2,204
Low-policy scenario	1,055	1,398	1,690	1,923

Source: China Climate Change Country Study, 1999.

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[8] The "China Climate Change Country Study" is hereafter referred to as the China Country Study.

[9] One ton of Chinese raw coal is equivalent to 0.7133 tons of standard coal equivalent.

A. INVESTMENTS IN COAL PRODUCTION

Regional Coal Balances

China's eastern region is densely populated and economically developed, making it the largest energy consuming region in the nation. (See Table 9 for a definition of each region.) In 1996, coal consumption in the eastern region was 371 million tons, of which about 45 percent was imported from other regions.

The northeastern region is home to China's aging industrial base. Annual coal imports to this region totaled 42 million tons in 1996. Coal consumption in that year was 210 million tons, while production was 168 million tons. More recently, coal consumption here has declined as factories and enterprises have shut their doors due to economic reforms and the impact of the Asian financial crisis.

In the southern and central regions, total coal consumption reached 284 million tons in 1996, of which 80 million tons were imported. In the same year, the southwestern and northwestern regions consumed approximately 170 million and 110 million tons of coal, respectively. These regions had excess supply and were able to export approximately 20 and 7 million tons, respectively.

China's northern region is the largest coal producing area in the country. It also ranks second in terms of coal consumption. In 1996, coal production reached 514 million tons. Local demand of 301 million tons allowed over 200 million tons to be exported to other regions.

Table 9 – Regional coal consumption in the policy scenario (million tons)

	1996	2000	2010	2030
North	301	303	342	547
Northeast	210	216	250	292
East	371	378	430	549
Central and South	284	293	310	382
Southwest	169	176	187	224
Northwest	111	118	149	210
Total	1,446	1,484	1,668	2,204

Regional definitions: *North*: Beijing, Tianjin, Hebei, Shanxi, western Inner Mongolia; *Northeast*: Liaoning, Jilin, Heilongjiang, eastern Inner Mongolia; *East*: Shanghai, Jiangsu, Zhejiang, Anhui, Shandong, Fujian; *Central and South*: Henan, Hubei, Hunan, Jiangxi, Guangdong; *Southwest*: Sichuan, Chongqing, Guizhou, Yunnan, Xizang (Tibet); *Northwest*: Shaanxi, Gansu, Ningxia, Qinghai, Xinjiang. N.B. Hainan and other Chinese islands are not included in this listing.

Source: Energy Research Institute

Coal reserves and production

China is a country with a rich coal endowment. Coal reserves less than 2000 meters below the surface amount to 5000 billion tons, of which about 40 percent were formed in the Jurassic Period and contain low sulfur content. Reserves within a depth of 1500 meters are approximately 3000 billion tons, mainly distributed in Shanxi province, western Inner Mongolia, and northern Shaanxi province.

Development of coal mines in China has varied with time and location. In the eastern coastal region, where coal reserves are minor and extensive mining has already occurred, the remaining proven coal reserve are low. In the central and western regions, where coal resources are abundant, remaining coal reserves are still large.

In the 1970s, intensive capital investment and mining production were concentrated in the east. Almost two-thirds of the nation's total coal production investment occurred here and it provided half of the national coal output. But coal demand increased rapidly with renewed economic growth in the 1980s and coal production from the eastern regions could not keep pace to supply the growing demand. During this period, coal production in China began to shift to the north and west.

It is estimated that in the eastern region, exploitable hard coal lying at 1000-meters or less remains at 50 billion tons, enough to build 500 million tons of new annual coal production capacity. (See Table 10.) Taking account of the recent production decline and retirement of existing inefficient mines, the greatest annual coal output in the eastern region will be 700 million tons in early next century.

In the north, coal reserves are currently estimated at 2200 billion tons, with coal reserves at less than 300 meters amounts to 154 billion tons. In the coming decades, the north region will continue to be the greatest coal producer, and will export coal to the eastern, southern, central and northeastern regions to bridge the demand gaps there.

In the southwestern and northwestern regions, coal production will mainly supply local markets and remain stable at an output level of less than 300 million tons annually.

Table 10 – Coal Reserve and Production by Region (Million Tons)

Region	**Proven reserves**	**Coal output**		
	1996	**2000**	**2010**	**2030**
North	365,000	606	730	1,110
Northeast	31,900	174	202	218
East	31,300	205	231	281
Central and South	30,500	214	240	285
Southwest	49,900	200	221	268
Northwest	21,900	62	80	125

Source: Energy Research Institute

Capital investment for coal production

Taking into account the reserve depletion and recent mine closures, Table 11 gives required new production capacity for the three scenarios in the China Country Study. The cumulative difference between the baseline and low-policy scenario amounts to over 1,500 million tons of production capacity each year.

Table 11 – Newly Commissioned Coal Production Capacity (Million Tons per year)

	1996—2000	**2001--2010**	**2011—2030**
Baseline	241	873	1,701

Policy scenario	83	594	909
Low-policy scenario	3	545	740

[Source: China Country Study?]

For coal mine construction, a long lead time is usually required, and capital investment varies with the individual situation of each mine. It is therefore difficult to accurately estimate the value of capital investment for coal mine construction. Modeling the expenditures using an assumed periodic investment smoothes the variation between year to year and mine to mine, providing a more creditable mean value. Table 12 shows capital investments of state owned coal mines during the 1980s, and Table 13 details the coal mine construction situation from 1986 to 1995.

Table 12 – Capital Investment of State Owned Coal Mine (Yuan per Ton Capacity)

	Large coal mine	**Middle coal mine**	**Small coal mine**
1980	112	76	98
1985	128	131	115
1989	183	199	103

Source: Energy Research Institute

Table 13 – Coal mine construction during 1986 to 1995

	1986—1990	**1991--1995**
Total capital investment* (billion current yuan)	38	79
Unfinished production capacity in the beginning of the period (million tons)	179	186
Newly invested production capacity (million tons)	118	135
Production capacity put into operation (million tons)	112	133
Unfinished production capacity in the end of the period (million tons)	186	159

* Including coal mine construction investment and coal washing plant construction investment.

Source: Energy Research Institute

Analysts at the Energy Research Institute estimated the amount of capital required to increase production capacity to the level estimated in the *Country Study*. They assumed that capital invested in a coal mine follows a linear relationship with capacity put into operation. Using this simplified methodology, they came up with the following relationships: 208 yuan per ton production capacity during 1986 to 1990, 312 yuan for new capacity commissioned during 1990 to 1995, and 417 yuan for some coal mines needing long construction period.

Taking the average capital investment during 1990 to 1995 as a standard, one can evaluate total capital investment needed for coal production, as shown in Table 14. It should be noted that these projections are based on costs from 1990 to 1995 and China's market for coal has changed considerably since then.

Table 14 – Total Capital Investment for Coal Production* (Billion Yuan)

	1996—2000	2001--2010	2011—2030	Total
Baseline	101	394	709	1204
Policy scenario	347	248	379	974
Low-policy scenario	1	227	309	537

* Including coal mine construction investment and coal washing plant construction investment.

Source: Energy Research Institute

Coal transportation volume

Coal transportation is an important element of China's energy system since centers of demand and supply are often far apart. In general, coal is transported from north to south and from west to east.

In the years in question, coal export areas include Shanxi, Shaanxi, Inner Mongolia, Ningxia and Xinjiang provinces, with Shanxi, Shaanxi and western Inner Mongolia counted as the major players. Coal import areas are concentrated along the east coast and in the northeast. In the southwest, coal produced in Yunnan province and Guizhou province can supply at least part of the demand in Sichuan, Guangdong, and Guangxi provinces.

Coal transported from Shanxi will growth from 255 million tons in 1996 to 402 million tons in 2030. (See Table 15.) The coal transported from Inner Mongolia will increase from 25 million tons in 1996 to 37 million tons in 2030. On the receiving side, coal transported to the eastern region will increase from 167 million tons in 1996 to 270 million tons in 2030, and, in the northeast, from 42 million tons in 1996 to 74 million tons in 2030. (See Table 16.)

Table 15 – Coal Export by Region Based on Policy Scenario (Million Tons)

	1996	2000	2010	2030
Shanxi	255	267	304	402
Inner Mongolia	25	26	31	37
Shaanxi	5	11	16	33
Ningxia	5	6	7	15

Source: Energy Research Institute

Table 16 – Coal Import by Region Based on Policy Scenario (Million Tons)

	1996	2000	2010	2030
Northeast	42	42	48	74
East	167	173	199	270
Central and South	79	80	83	112
Southwest	19	21	28	29

Source: Energy Research Institute

Coal transportation routes

As mentioned above, all coal export areas are located inland, far from ocean waterways. Rail is therefore the chief means of moving the coal. Transporting coal on barges and in trucks are two important supplemental measures. In 1997, China's coal output was 1.4 billion tons, of which only 29.2 percent was consumed locally. Thus, 991 million tons of coal were transported between provinces and between cities. In that year, China's railroads moved about 75 percent of this coal, or 743 million tons worth. Road transport was next with just over 104 million tons, or 10.5 percent. Coal transported by a combination of rail and water barge amounted to about 10 percent of the total, or 98 million tons. (See Table 17.)

Table 17 – Coal Transportation Volume Based On Policy Scenario (Million Tons)

Channel	**1996 (actual)**	**2000**	**2010**	**2030**
Railway	721	770	883	1,171
Road	100	108	124	164
Water way*	93	149	170	226

* Including joint rail and water transportation.

Source: Energy Research Institute

Major rail trunk lines in the north include: Beijing—Baotou, Beijing—Taiyuan and Datong—Qinhuangdao. These railways, running from west to east, transport coal from Ningxia, Western Inner Mongolia, northern Shanxi and central Shanxi to Beijing, Tianjin, and nearby Bohai harbors.

Rail trunk lines in the center of China include: Shijiazhuang—Taiyuan, Handan—Changzhi, Handan—Nanchang, Shijiazhuang—Shuozhou, Shijiazhuang—Hengshui, and Beijing—Jiulong (Kowloon, in Hong Kong). These lines, running from north to south, transport coal from Shanxi to eastern coastal areas, central and southern areas, and key harbors in Qingdao, Lianyungang, Rizhao, and others along the Yangtze River.

Southern trunk lines include Taiyuan—Jiaozuo, Nantongpu railway, Jiaozuo—Zhijiang, Beijing—Guangzhou, and Longhai railway. These lines transport coal from southeastern Shanxi, southern Shanxi, northern Weihe River, western Henan to eastern coastal areas, central and southern areas, Qingdao Harbor, Lianyungang Harbor, Rizhao Harbor and several Yangtze River harbors.

Besides these rail lines which move coal to the east and south, a few lines go west and transport coal from Ningxia, western Inner Mongolia, northern Weihe River, western Henan and southeastern Shanxi to Sichuan and Gansu.

In recent years, road transportation has begun to play an increasingly important role for short distance coal transportation within a province or to nearby provinces.

Capital investment for coal transportation

In this section we estimate the investment costs required to build transportation infrastructure to the levels forecasted in the China Country Study. These estimates are complicated due to the fact that railways, water ways, and road transportation systems are linked, and other freight transport will put additional requirements on the infrastructure system.

Table 18 shows typical investments for railroads recently constructed. If we assume that all new coal transportation lines are electric, investment per kilometer per ton of transport capacity averages 25,800 yuan.

Table 18 – Railway Investment Recently Constructed

Railway	**Distance (km)**	**Transportation Capacity (million tons)**	**Investment (billion yuan)**	**Unit investment (yuan per kilometer per ton)**
Dacheng	345	7	3.4	1.4
Dawan	158	5	2.7	3.4
Shuibai	121	3	1.0	2.7
Jinwen	305	3	2.8	3.1
Average				2.4
Incremental investment for electrification				0.5
Estimated investment				2.9

Source: Energy Research Institute

To estimate the total investment needed to meet the needs outlined in the China Country Study, we estimate the average distance as explained below and the amount of coal to be transported as shown in Table 17. From 1996 to 2000, the average coal transport distance is estimated at 555 kilometers (rising from 554 kilometers in 1997 and 553 kilometers in 1998); from 2001 to 2010, it rises to 570 kilometers; from 2011 to 2020, 580 kilometers; and from 2021 to 2030, 600 kilometers. Table 19 gives the capital investment to enlarge transportation capacity correspondingly. Note that these estimates are based on costs in the year 1996 and are likely to change.

Table 19 – Capital Investment for New Railway Transport Capacity (billion current yuan)

	1996—2000	**2001—2010**	**2011—2030**	**Total**
Baseline	184	537	906	1,627
Policy scenario	52	318	314	684
Low-policy scenario	0.0	249	207	456

Source: Energy Research Institute

Investment for water transportation is even harder to forecast. ERI estimates the investment costs of a newly built berth for 500-ton ship at about 70.4 million yuan. Harbor facility costs would add another 35.2 million yuan. Annual coal turnover capacity would be 375 thousand tons. Considering harbors for loading and unloading, we roughly estimate that the investment for water transportation is 563 yuan per ton capacity. Total investment for enlarging water way coal transportation as required is estimated as shown in Table 20. Note that these are only costs for the harbors themselves; other costs would also be required.

Table 20 – Capital Investment for Harbor Construction (billion current yuan)

	1996—2000	2001--2010	2011—2030	Total
Baseline	44	37	60	142
Policy scenario	35	22	21	78
Low-policy scenario	30	17	14	61

Source: Energy Research Institute

B. INVESTMENT FOR OIL AND GAS EXPLORATION

At the beginning of the next century, the main efforts in oil exploration will focus on the eastern and western Songliao Basin, Bohai Gulf Basin, Tarim Basin, and Junggar Basin. Approximately 70 percent of the nation's remaining oil reserves are believed to lie in these regions. Natural gas exploration will focus on the central and western regions of China, where about 80 percent of the remaining on-shore reserves are believed to be located based on current understanding. The major exploitation sites are located in the Tarim Basin, Sichuan Basin and Ordos Basin, which make up more than 60 percent of the total on-shore reserves.

Current proven oil and gas reserves located offshore are low, accounting for only 3-4 percent of the total estimated offshore reserves. There is thus a huge potential to confirm additional offshore oil and gas reserves. The major areas for offshore oil exploration are located in the Bohai Sea and in the depression zone in the mouth of the northern Zhujiang (Pearl) River. As currently understood, the main areas for natural gas exploration are located in the western continental shelf of the northern South Sea, Xihu Depression in the East Sea, and three gas-bearing areas in the Bohai Sea.

It is expected that from 2000 to 2030, the annual increment of proven oil reserves will range from 500-600 million tons, and that of natural gas 200 billion cubic meters. The total investment costs for oil and gas exploration will amount to 600 billion yuan.

Investment for oil development

In the coming decades, the basic measures to support China's onshore oil production include: halting the output decline at existing oilfields, increasing oil and gas recovery by employing advanced technologies, shortening construction time in new exploitation areas, increasing capital investment in western oilfields. Chinese planners estimate that onshore oil output will remain stable or increase slightly before 2015, and decline slowly after that. Onshore oil output will be 168 million tons in 2010, 143 million tons in 2020, and 126 million tons in 2030. The total capital investment will be 328 billion yuan from 2000 to 2010 and 525 billion from 2011 to 2030.

In the first ten years of the next century, reducing output decline and speeding up the preparation of new field exploitation will be the major tasks of offshore oil development. After 2010, a steady increase of oil output will depend on investments in newly proven reserves. Offshore oil output will steadily increase between 2000 and 2030. It is predicted that production in 2010, 2020 and 2030 will be 20 million tons, 25 million tons and 30 million tons, respectively. The total investment needed will be 51 billion yuan from 2000 to 2010 and 141 billion yuan from 2011 to 2030.

Investment for natural gas exploitation

Forecasters predict that onshore natural gas output will reach 63 billion cubic meters by 2010, 75 billion cubic meters by 2020, and 90 billion cubic meters in 2030. Over these respective time periods, the total capital investment for increasing natural gas output will be 78 billion yuan, 94 billion yuan and 143 billion yuan.

It is expected that by giving priority to offshore natural gas exploitation, rapid development of offshore natural gas production will occur over the next 30 years. The offshore natural gas output will be 23 billion cubic meters in 2010, 30 billion cubic meters in 2020 and 40 billion cubic meters in 2030. The periodic investment will be 36 billion yuan, 47 billion yuan and 62 billion yuan accordingly.

Domestic supply and demand

Yawning gaps between the supplies of oil and natural gas and their associated demands appear in the three scenarios. (See Table 21.) Energy imports will be needed to close these gaps. By 2030 in the baseline scenario, China will be importing more than twice as much oil as it currently consumes, while the low-policy scenario would cut that amount in half.

Table 21 – Gaps between Oil and Gas Supply and Demand

Year	**Baseline**		**Policy scenario**		**Low-policy scenario**	
	Oil (Mt)	Gas (billion m^3)	Oil (Mt)	Gas (billion m^3)	Oil (Mt)	Gas (billion m^3)
2010	173	--	100	--	82	--
2020	274	21	172	15	141	5
2030	384	56	245	48	197	34

Source: Energy Research Institute

Oil supply and demand balances vary according to region in China. In the northeast and northwest, output can meet regional demand with enough left over for exports to other regions. In the north and southwest, oil demand can not be satisfied with regional output. The gap in the north will grow from 10 million tons in 2010 to 35 million tons in 2030. The gap in southwest will increase from 4 million tons in 2010 to 12 million tons in 2030. Excess production in the northeast can largely meet demand in the north, while the northwest can likewise transport oil to the southwest. However, for central, south, and east China, domestic oil output can supply only a small part of oil demand there. Cross border imports to these regions are expected to grow rapidly. (See Table 22.)

Table 22 – Oil gaps in Central and South China and East China (million tons)

Year	Baseline		Policy scenario		Low policy scenario	
	Central and South	East	Central and South	East	Central and South	East
2010	119	87	87	67	81	61
2020	146	121	110	87	98	77
2030	183	154	132	108	114	92

Source: Energy Research Institute

China's natural gas industry is undergoing rapid change after decades of near dormancy. There is growing recognition that domestic gas and coalbed methane could play a much larger role in meeting China's energy needs, although the speed at which market demand develops will depend on the establishment of new reforms and regulations.

Oil and gas transportation

To transport oil from the northwest to the southwest, three pipelines will be built: Shanwu, Wupeng, and Wuji. The length of the pipelines total 4000 kilometers and capital investment is estimated at nearly 15 billion yuan.

China has recently started to cooperate with neighboring countries on joint oil and natural gas development. Pre-feasibility studies have been conducted for one oil pipeline and three gas pipelines.

IRKUTSK-MANZHOULI-DAQING OIL PIPELINE

The Irkutsk -Manzhouli-Daqing oil pipeline would be 3000 kilometers long with a maximum annual transportation volume of 50 million tons. The pipeline section inside China, from Manzhouli to Daqing, would be 850 kilometers long, requiring $500-650 million in investment. Researchers in China envision that this pipeline will transport 30 million tons of oil a year by 2005, and reach its maximum of 50 million tons by 2010.

IRKUTSK-BEIJING NATURAL GAS PIPELINE

This pipeline would connect the rich natural gas fields near Lake Baikal in Russia with Beijing. It would extend approximately 4000 kilometers, with the section inside China accounting for nearly 40 percent of the entire length. Total construction cost is estimated at $1.5 to1.8 billion dollars. The pipeline would be used primarily to supply natural gas to civil and industrial gas markets in the Bohai Gulf area and in northeastern China. The annual gas transportation capacity would be 20-30 billion cubic meters.

WEST SIBERIA-URUMQI-SHANGHAI NATURAL GAS PIPELINE

This pipeline is envisioned to run from western Siberia in Russia to Shanghai via Urumuqi. Annual gas import capacity would be about 30 billion cubic meters. Total transportation capacity of the pipeline within China's borders could be 40 billion cubic meters per year, if the natural gas produced at the Tarim Oilfield is connected to the same pipeline. This volume could meet much of the natural gas demand in east China for the foreseeable future. The pipeline would total 6870 kilometers in length and require up to $13.5 billion in capital investment, with two-thirds of that amount needed for pipeline construction within China's borders.

MIDDLE ASIA-URUMUQI-LIANYUNGANG NATURAL GAS PIPELINE

This proposed pipeline would begin in Turkmenistan or Uzbekistan and end at Lianyungang in northeastern Jiangsu province. The length would total 5730 kilometers with an estimated capital requirement of $10-12 billion dollars. The pipeline would have an annual import capacity of 20 to 30 billion cubic meters, but maximum capacity within China's border would reach 30 to 40 billion cubic meters when natural gas produced in western China is connected to the system.

IMPORT TRADING VOLUME OF OIL

Under current development trends, central, south, and east China will face serious oil shortages in the future. Supply-demand gaps in central and south China range from 81 million tons in the low-policy scenario in 2010 to 183 million tons in the base plan for 2030. In east China, the shortage ranges from 61 million tons in 2010 in the low-policy scenario to 154 million tons in the base plan for 2030. Over the next 30 years, in addition to the oil imported through Russian oil pipelines, an additional 70-80 million tons of oil could be imported from Southeast Asia. The remaining demand would probably need to come from the oil produced in the Middle East. For this reason, while fully utilizing the handling capacity of existing ports, three to five additional ports with an annual handling capacity of 50-70 million tons should be built. Total estimated investment for these ports is estimated to be $5-6 billion dollars.

In the coming 30 years, the proposed oil and gas pipelines could handle a maximum annual import capacity of 50 million tons of oil and 60-70 billion cubic meters of natural gas. But in 2030 gaps of 197 million tons and 334 million tons will remain, which must be satisfied by import from other channels.

C. TECHNOLOGY OPTIONS FOR POWER GENERATION

China's electric power industry has developed very quickly over the last three decades. Total installed capacity increased from 24 GW in 1970 to 138 GW in 1990, and 254 GW in 1997. During the 1990's, installed capacity increased by about 15 GW annually, the equivalent of adding a 565 MW plant every two weeks. Despite a downturn in demand during the late 1990s, robust growth in electricity consumption is expected to continue in the coming decades.

Currently, thermal power plants account for over three-quarters of China's installed capacity. Hydro and nuclear power provided about 24 and less than 1 percent of capacity, respectively.

Thermal power generation

China's electric power industry is based on low-cost, plentiful domestic coal supplies and locally made power generation technologies. For these reasons, coal now supplies the vast majority of electric power production. In 1997, coal power generation accounted for 92 percent of total thermal power generation while oil and gas made up the remaining 8 percent.

Almost all methane-rich gas used from power generation came from byproducts of industrial applications.

China can manufacture conventional pulverized coal fired generation units at a cost of approximately 5500 yuan per kilowatt ($663/kW), 10 to 30 percent cheaper than most industrial countries. China is capable of domestically manufacturing turbine units of up to 300 megawatts, and units up to 600 megawatts have been produced in joint ventures in China. Currently, 300 and 600 megawatt sub-critical units are becoming the backbone of the generation system. The efficiency of domestically produced thermal units is gradually improving. It is expected that the efficiency of large domestically produced coal-fired power generation units will rise to nearly 40 percent early in the next century with intensified technology transfer and research and development programs.

In the coming decades, pulverized coal-fired units will likely remain the chief source of coal-based power generation in China, although environmental concerns may accelerate the penetration of other cleaner technologies. About one-third of China's sulfur dioxide and particulate emissions come from combustion of coal for power generation. Compared with other coal utilization equipment and facilities, such as industrial boilers, kilns and furnaces, and household coal stoves, pollution emission controls in coal-fired power generation are comparatively cost effective, and are therefore implemented more strictly.

PARTICULATE EMISSION CONTROL AND ASH UTILIZATION

China's electric power industry has made notable progress in particulate emission control. In 1990, the total installed capacity of coal-fired power plants with unit capacities over 6 megawatts was 76 GW, and particulate emissions totaled 3.6 million tons. By 1997, installed capacity had increased to 171 GW, while particulate emissions increased by only 11 percent to 4.0 million tons. The average particulate removal rate increased from 92 percent in 1987 to 96 percent in 1997. By 1997, 78 percent of thermal capacity was equipped with high efficiency precipitators, of which 55 percent were electrostatic precipitators.

Typical costs for new precipitators in China designed to remove up to 99.7 percent of particulate ranges from 250 yuan to 500 yuan per kilowatt. Effective precipitators add only 2 percent or so to the cost of power. As all new, expanded, and renovated thermal power plants were required to be equipped with high-efficiency precipitators, they have become a necessary part of all thermal power plants. Therefore, investment costs for precipitators will be included as part of the capital costs of conventional generation units hereafter.

The government has also implemented policies to promote utilization of ash and slag from coal-fired power production. China stopped direct discharge of ash and slag to rivers and lakes in 1995. Ash and slag utilization increased from 11 million tons in 1987 and to 70 million tons in 1995, most being used in the production of building materials. Markets for ash and slag utilization have recently emerged and are becoming profitable industries.

SULFUR EMISSION CONTROL

Reducing sulfur dioxide emissions is the most critical environmental task for China's electric power industry. Large-scale coal-fired boilers, most of which are for power generation, can control sulfur dioxide emissions more cost-effectively than in other sectors. China has built several pilot plants equipped with flue gas desulfurization (FGD) equipment with varying degrees of success. The total installed capacity of the plants totals little more than 1 GW. China had planned to install desulfurization equipment on 10 GW of coal-fired capacity by 2000, but this target may now be difficult to achieve. These plants do not play a significant role in sulfur emissions control, but they are starting points for future.

In 1995, the People's Congress revised the Air Pollution Prevention Law, which strengthen the control not only of sulfur dioxide concentrations but also of total emissions. The Law states that if newly constructed thermal power plants can not use low sulfur coal (sulfur content<1 percent), they must be equipped with necessary desulfurization equipment or other emission control measures must be adopted.

Wet scrubbers can remove over 90 percent of the sulfur dioxide from power plant flue gas. More can be removed with additional additives. Wet scrubbers usually add about 20 percent to power plant capital costs or 1,000 yuan per kilowatt. China has yet to develop its own domestic wet FGD technology, and imported units have demonstrated considerable operational problems. Dry scrubbers generally remove less sulfur dioxide than wet scrubbers--only about half to seventy percent--although dry scrubbing is cheaper and simpler than its wet counterpart, costing about 700 yuan per kilowatt.

IGCC

Integrated gasification combined cycle (IGCC) power plants—which first gasify coal and then burn the methane-rich gases in a combined-cycle system—can operate at higher efficiencies and produce less pollution than traditional pulverized coal power plants. Energy planners in China believed that IGCC could help solve the country's power problems because this technology can use domestic coal without creating the same environmental side effects. IGCC plants, however, are complex and expensive. The efficiency of current IGCC technology ranges from 42 to 45 percent while emissions of sulfur dioxide are virtually eliminated.

China is planning to construct an IGCC demonstration project using technology from western countries. Capital cost estimates are currently about 11,000 yuan per kilowatt for IGCC. To commercialize IGCC technology and spread its use, costs would need to decline significantly and operational difficulties would need to be overcome. Chinese planners believe that IGCC capital costs will decline to 8,500 yuan per kilowatt by 2010.

PFBC

Pressurized fluidized bed combustion (PFBC) systems—as the name implies—burn coal on a fluidized bed under high pressure so more complete combustion can occur. Prior to combustion, the coal is crushed and mixed with a calcium-based agent such as limestone to reduce sulfur emissions. Efficiencies of up to 45 percent can be achieved although large plants have not yet become commercially available due to technical difficulties. China began research on PFBC systems in 1980 and constructed a 15-megawatt demonstration unit in Jiangsu in 1991. China plans to build another 100-megawatt demonstration plant in the near future, followed by a 300-megawatt unit.

Chinese researchers believe that imported PFBC systems would have high capital and O&M costs, slowing their diffusion across the country. Capital costs for a 200-megawatt unit are estimated at 10,000 yuan per kilowatt. The initial plants would likely cost much more. It is expected that PFBC systems will be commercialized in China by 2010, becoming cheaper after that.

GAS AND OIL FIRED COMBINED CIRCLE SYSTEMS

Combined-cycle power plants fueled by natural gas, LNG, or light oil have many advantages over coal-fired electric power generation. Advanced combined-cycle systems operate at approximately 55 percent efficiency and have become the choice of power planners in many regions of the world where gas is available. Combined-cycle units are popular because of their low capital costs, modularity and flexibility, short construction periods, dependability, and relatively clean operation. In China, distorted markets for natural gas and the lack of transmission and distribution infrastructure have prevented greater use of this fuel in generating power.

The high-efficiency of combined-cycle units may offset the price advantage coal has over gas in a few regions where coal is relatively expensive and low-cost natural gas is available. Current estimates of investment costs of mid- and large-size combined cycle systems range from 3,800 to 7,000 yuan per kilowatt. O&M costs for combined-cycle plants in industrialized countries are generally lower than coal-fired units and capacity factors are higher.

For combined-cycle units to play a larger role in power generation in China, new policies and regulations would need to be adopted. Natural gas prices need to be set to provide incentives for domestic exploration and production (Logan and Chandler).Gas transmission and distribution infrastructure needs to be built to bring gas to markets, and end-users need more incentive to switch from coal to gas. A clear policy for imported pipeline and liquefied natural gas needs to be established if domestic resources are deemed insufficient. These policies must be coordinated together, making the task more difficult.

HYDROPOWER GENERATION

China has the most abundant hydropower resources in the world, with an estimated potential of over 300 gigawatts. Currently installed hydropower capacity is just over 50 gigawatts, about 15 percent of the potential. China has a program to build many large hydropower stations over the next 20 years, most of them on the mid- and upper-reaches of the Yangzi, Yellow and Lancang Rivers. China's richest hydropower resources lie in the southwest, far from the population centers along the east coast. (See Table 23.)

Table 23 – Hydropower Resource in China by Region (GW)

	Exploitable Capacity	1997 Installed capacity	Exploitation Rate (percent)
North	52	14	26
East	13	8	61
Central	52	18	34
Southwest	196	22	8
Total	313	62	19

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

Source: Energy Research Institute

China has the capacity to domestically produce all but the largest hydropower turbines using its own technology. It can also design and construct all varieties of large hydro power projects, including the Three Gorge Dam, the largest hydropower project in the world. Construction of hydropower projects is capital intensive, expensive, and controversial, even in China. Capital costs for large hydropower turbine projects range from 8,000 yuan per kilowatt to over 10,000 yuan per kilowatt, depending on the specific situation of individual projects. Small and mini-hydro turbines are cheaper than the larger units, costing approximately 7,000 yuan per kilowatt, but the savings are usually offset by lower availability for power generation.

NUCLEAR POWER GENERATING TECHNOLOGIES

China plans to make greater use of nuclear power along the east coast where local energy supplies are scarce, but high costs and financing difficulties have slowed progress. Three reactors are currently in operation with 2,100 megawatts of capacity. In 1997, nuclear reactors generated about 14 terawatt-hours of power, accounting for about 1 percent of all generation. Four other plants with a combined capacity of 6.7 GW are expected to be on-line by 2005. (See Table 24.)

Table 24a – China's Nuclear Power Plants

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

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

* - planned.

Source: Battelle Memorial Institute.

Table 24b – China's Nuclear Power Plants

Plant	Location	Net Output (MWe)	Initial criticality	Commercial start	Utility	Reactor Supplier	Steam Generator Supplier	Architecture	Construction
Operational									
Qinshan 1	Haiyan, Zhejiang	300	10/91	6/94	Qinshan Nuclear Power Corp.	CNNC, Japan (Mitsubishi)	CNNC	CNNC	CNNC
Daya Bay	Daya Bay, Guangdong	(unit 1) 900 (unit 2) 900	7/93 1/94	2/94 5/94	Guangdong Nuclear Power Joint Venture	France (Framatome)	France, UK (GEC-Alsthom)	Alsthom, Electricite de France, General Electric, others	Campenon-Bernard, China Construction Engineering Corp, Huaxing, Maeda, others
Under Construction									
Qinshan 2	Haiyan, Zhejiang	(unit 1) 600 (unit 2) 600		2002 2003	Qinshan Nuclear Power Corp.	CNNC, South Korea, France, others	US (GE)	China, France	China
Qinshan 3	Haiyan, Zhejiang	(unit 1) 700 (unit 2) 700		2003 2004	Qinshan Nuclear Power Corp.	Canada (AEC)	Japan (Hitachi)	US (Bechtel)	Canada, China, South Korea
Ling'ao	Ling'ao, Guangdong	(unit 1) 900 (unit 2) 900		2003 2003	Guangdong Nuclear Power JV	France (Framatome)	France, UK (GEC-Alsthom)	France, UK	China, France, Japan
Lianyungang	Lianyungang, Jiangsu	(unit 1) 1000 (unit 2) 1000		2004 2005	Lianyungang Nuclear Power JV	Russia, Germany	Russia	Russia	China, Russia

N.B. All plants are PWRs. Canadian-built reactors are CANDUs.

Source: China Energy Project data, Lawrence Berkeley National Laboratory, 1997.

Nuclear power plants could avoid many of the environmental problems associated with coal combustion, although they pose their own problems of a different magnitude. Some countries, such as Korea and France, depend heavily on nuclear power generation. Japan and Korea, in particular, have constructed many nuclear power plants over the past two decades to reduce dependence on imported fossil fuels.

China currently has the capability to manufacture about 70 percent of the components of advanced pressurized water reactor systems. It imports the remaining 30 percent to meet technical requirements. On average, new pressurized and boiling water reactors in China have capital costs of 15,000 yuan per kilowatt. China hopes to localize these technologies and thus bring costs down to about 12,000 Yuan per kilowatt within a decade.

GRID-FED WIND FARMS

China has reserves of 253 GW of wind power, much of it located in Inner Mongolia, Xinjiang and the eastern coastal regions. Wind installations will accelerate over the near term as pollution control becomes more important.

Wind turbine systems have capital costs around 8,000 yuan per kilowatt or less. The Chinese government plans to introduce foreign licenses and localization of wind turbines to lower costs. It is anticipated that wind turbines mass-produced in China could make this power source available for 4,000 yuan per kilowatt, competitive in some areas with coal-fired units. More information on grid-fed wind farms, and other renewable energy options described below, is found in the final section of this report.

OTHER RENEWABLE ENERGY POWER GENERATION

By 1997, China had installed solar photovoltaic, geothermal, and ocean tidal power stations totaling 6, 32, and 11 megawatts of capacity, respectively. These technologies are expected to play more important roles in local and niche markets, although costs will have to come down significantly for them to become commercial technologies with sizeable market share.

Mini wind turbines

In China, over 140,000 mini wind turbine (60-200 watt) units operate in rural and remote areas. Government forecasters estimate the total installed capacity of mini wind turbines will be 140 megawatts in 2020 with total power generation of 450 GWh, respectively, which will significantly reduce the number of people currently not connected to power grids.

Photovoltaics

China has large solar energy resources, most of which are concentrated in western China. Solar radiation in western China is strong throughout most of the year and falls in regions of sparce population. More than 7 megawatts of PV cells are currently in use in rural China. Costs of PV are dropping rapidly from today's level of approximately 37,000 per kilowatt. New thin-film PV cells will have lower costs, greater efficiency, and longer life than traditional silicon-based cells, making them priority research topics for Chinese scientists.

Biomass

Biomass energy provides 220 million tons of coal equivalent each year and is used mainly in rural areas. Economic growth and urbanization will shift demand from biomass to high-quality energy sources; less biomass energy will be used directly as main fuels for heating and cooking in households in rural areas.

In developed nations, most biomass plants are used in combined heat and power systems. China has the potential to rapidly develop key biomass technologies that could double conversion efficiencies and make biomass an attractive source of energy for both industrial and utility applications in rural areas.

Geothermal power and other renewable energy

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

China will continue to exploit geothermal heat sources to generate power in Tibet and Yunnan. While geothermal plants are competitive in these regions, they will not likely play a major role in other areas over the time period of this study.

A number of other technologies including tidal, ocean thermal gradient, and solar thermal power exist and China will probably continue to develop these sources as appropriate. Limited supplies or other technical and financial barriers will inhibit wide-scale application in China, and so are beyond the scope of this study.

Capital investment of three scenarios

Table 25 summarizes newly installed capacities in the three scenarios of the China Country Study. Based on per unit capital investment evaluated above, Table 26 presents the capital investment estimates for constructing these capacities. Note that operation and maintenance, fuel, and environmental costs are not included in these estimates so they provide only a partial picture.

Table 25 – Power Capacity Forecasts (GW)

Period		1991--2000	2001--2010	2011--2030
Baseline	Thermal	122	180	224
	Hydro	35	28	87
	Nuclear	3	18	78
	Renewable	1	2	39
	TOTAL	161	228	428
Policy	Thermal	106	119	64
	Hydro	46	65	103
	Nuclear	3	28	168
	Renewable	1	1	79
	TOTAL	155	213	414
Low-policy	Thermal	97	84	64
	Hydro	45	52	105
	Nuclear	3	25	113
	Renewable	1	1	49
	TOTAL	146	163	331

Source: China Climate Change Country Study, 1999.

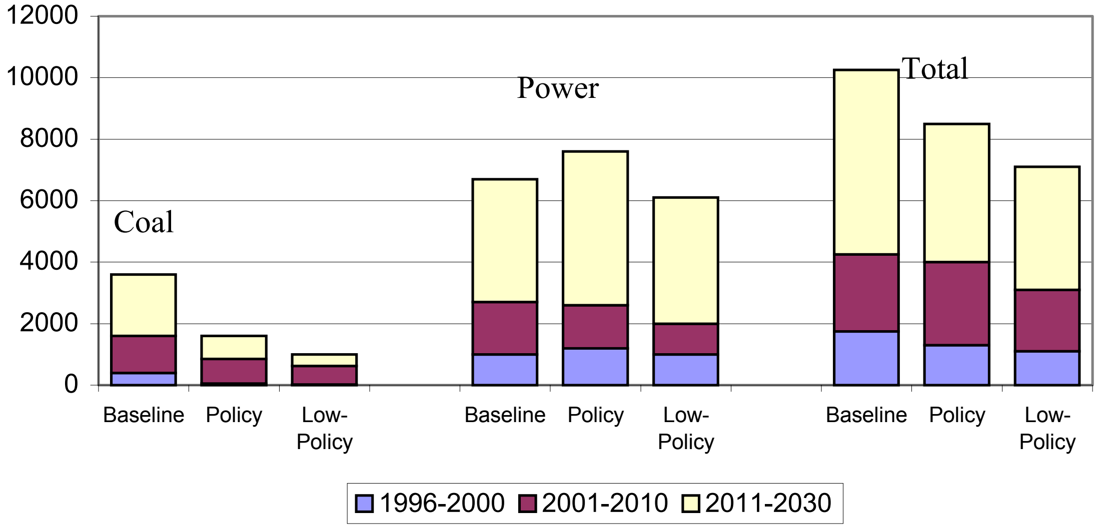
Table 26 –Capital Investment Required for Power Plants (Billion Yuan)

Period		1991—2000	2001--2010	2011--2030
Baseline	Thermal	671	1260	1904
	Hydro	280	280	870
	Nuclear	45	216	936
	Renewable	4	12	312
	TOTAL	1000	1768	4022
Policy	Thermal	584	834	546
	Hydro	449	938	1162
	Nuclear	45	330	2010
	Renewable	5	11	631
	TOTAL	1083	2113	4349
Low-policy	Thermal	535	591	545
	Hydro	443	704	1201
	Nuclear	45	303	1352
	Renewable	5	11	388
	TOTAL	1028	1608	3486

D. TOTAL INVESTMENT FOR NEW ENERGY INFRASTRUCTURE

Summarizing the estimated costs provided above, we can calculate the total capital investment required under the three scenarios as shown in Figure 2. Note that this figure only provides investment costs for coal development and power generation. Day-to-day operational costs are not included, nor are fuel costs for power generation.

Figure 2 – Total Investment Costs under the Three Scenarios



From the figure, we can see that in the coming years in China, the investment for power generation will be very high. In the baseline scenario, the investment for power generation will be twice as much as that for coal production and transportation, and for the other two scenarios, the investment for power generation will be up to 5 or 6 times higher. Such results means that in the coming years, raising capital sources for power generation will still be a big challenge in China.

Comparing the baseline with the policy scenario, we see that the investment for coal production and transportation in the latter drops sharply. At the same time, power investment rises due to the substitution of more expensive nuclear power. In the low-policy scenario, both the investment for coal production and transportation, and the investment for power generation drop. The total investment is much less than the investment required by baseline.

Except for a few oil and gas pipelines, it is difficult to estimate the capital investment required for oil and gas infrastructure in the near future. More and more oil imports are an unavoidable trend in China, even if the absolute amount of imports differs in the three scenarios. Such differences will influence the amount of oil and gas shipping oversea, and therefore influence the harbor turnover capacity needed, however they will not have big influence on the capital investment for inland oil and natural gas transportation systems mentioned above.

E. SECTION II REFERENCES

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III. The Status and Potential Contribution of Renewable Energy Technologies in China

For resource and environmental reasons, improved efficiency and non-fossil energy sources are key elements in a sustainable energy future. This section surveys the cost and quantity of energy that could be supplied in the coming decades by renewable energy technologies such as photovoltaics, solar thermal, biomass, hydropower, and wind, along with emerging new sustainable technologies such as hydrogen fuel cells.

A. OVERVIEW

China has considerable potential to exploit renewable energy resources. Available hydropower, wind, biomass, and other renewable resources, if harnessed, would theoretically be more than sufficient to meet China's current and future energy demand. The regions with greatest potential for power generation using renewable energy are distributed all across the country, and most areas have at least one significant resource (See Table 26.) Each resource is covered in more detail in the sections below.

Table 26 - Areas with Greatest Resource Potential for Renewable Power Generation

Resource	Criteria for Selection of Areas	Areas with Significant Potential	
Small Hydro	Provinces with remaining potential >1 GW	North & West:	Shanxi, Xinjiang, Qinghai,
		East:	Zhejiang
		Central:	Hunan, Hubei, Jiangxi
		South:	Guangdong, Fujian, Guizhou
		Southwest:	Tibet, Yunnan, Sichuan
Wind	W_{ave}>200 W/m^2, V>3 m/s for >5,000 hrs/yr	Northeast:	eastern Heilongjiang and Jilin
		Northwest:	northern Inner Mongolia and Gansu, Xinjiang
		Southeast:	SE coast and 6,300 islands
Solar	Class I and Class II, >3,000 hrs/yr, >5 GJ/m^2-yr	North:	northern Hebei and Shanxi, Inner Mongolia
		Northwest:	Ningxia, mid-northern Gansu, southern Xinjiang, Qinghai
		Southeast:	southeastern and western Tibet,
Geothermal	High Temp, >150°C	Southeast:	Fujian, Guangdong, Taiwan
		Southwest:	southern Tibet, western Yunnan and Sichuan
Biomass	Bagasse, forest residues	South:	Yunnan, Guangdong, Guangxi

Source: The World Bank, 1996.

More than most developing countries, China has made significant—and relatively successful—efforts to promote renewable energy use, particularly as an adjunct to the overall program for rural development. China expects to have around 20 GW of renewable power generation capacity in 2000 (mainly small hydro; excludes large hydro), or over 7 percent of total installed capacity (Table 27; The World Bank, 1996). Adding in electricity from large hydropower projects, direct use of biomass fuels and solar heat, one quarter of China's energy is supplied by renewable sources (RTCCCCS, 1999).

If recent trends continue, non-biomass renewables will continue to make up a significant portion of China's energy mix in the near to medium term. In the long run, although even the most optimistic projections predict only a minor role for renewables over the next several decades (e.g., RTCCCCS, 1999), there is hope that renewables may represent a growing share of total energy. This would be consistent with a recent statement that China hopes to cut the overall share of coal in the energy supply mix by 15 to 20 percentage points within 20 years.[10] Such an outcome requires further progress in supporting development of renewable energy markets and industries.

Table 27 - Current and Future Installed Capacity of Renewable Power Generation, MW

Technology	Actual Total in Operation, 1993	Planned Total in Operation by: 2000	2010	2020
Small Hydro	10,055	19,850	27,880	39,158
Wind	30	400 [1]	3,170	8,500
Solar PV	3	35	200 [2]	500
Solar Thermal	0	35	-	-
Geothermal	31	106	200	330
Biomass	87	n/a	n/a	n/a
Ocean	0	0	200	400
Total	15,211	20,726	31,650	48,888
Avoided Carbon Emissions (MtC) [3]	15	20	27	38

[1] While plans originally called for installed capacity of 1 GW by 2000, actual capacity by the end of 2000 is likely to be under 400 MW.

[2] Includes both solar PV and solar thermal.

[3] Assumes that the average capacity factor is 0.5, renewables replace coal-fired power generation, efficiency of coal-fired power generation improves by 2% per year, and the carbon emissions factor is 25.8 kgC/GJ coal.

N.B. Excludes large-scale hydropower capacity.

Source: The World Bank, 1996, based on renewable Energy Development Program and Ministry of Electric Power (now Sate Power Corporation) plans.

B. HYDROPOWER

If all technically and economically feasible hydropower resources were exploited, China could install 290 GW of hydropower capacity, and generate nearly 1,300 TWh/yr, slightly more than the 1,160 TWh generated by all power plants in China in 1998 (Sinton *et al*., 1996; SSB, 1999). The greater part of these resources are in southwestern China, which has two-thirds of the country's potential capacity. At the end of 1998, China had 65 GW of installed hydropower capacity, representing 24 percent of total generating capacity. This share has been on the rise, as large hydropower projects, many built with significant foreign assistance, have come on line.

A significant portion of China's future power generation will come from hydropower projects, if only because of construction of the Three Gorges Project on the Yangtze River, and other projects under construction and in planning that have capacities of 5 GW or more. Most of these plants will lie on the mid- and upper-reaches of the Yangzi, Yellow and Lancang Rivers. Long-range plans call for a total of 200 GW of hydropower in 2030 (RTCCCS, 1999). As in the past, small and microhydro projects will be the major source of power for many remote rural areas. These resources account for about 13 percent of total potential annual generation.

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[10] Zhou Fengqi, Director, Energy Research Institute (China), quoted in Bloomberg News, 4 August 1999. If coal use continues to fall, as it has for the past two years, the share of renewables will become more prominent.

China is, for the most part, self-sufficient in hydropower technology. Even though China is able to manufacture all but the largest hydropower turbines domestically, construction is capital intensive and expensive. Current capital costs for hydropower turbines range from \$950/kW to over \$1,200/kW.[11] Total project costs can be much higher. The Three Gorges Project, although not designed solely as a power project, may cost \$1,600/kW or more.[12] In some cases, several small dams can provide as much electrical output as a large dam, but without the extraordinary environmental impact (Battelle Memorial Institute, 1998).

Mini-hydropower plants typically rely on run-of-the-river configuration and do not require reservoirs. While this eliminates many of the environmental impacts of larger dams, it also makes the dam subject to low availability in the dry season. Capacity factors for most mini-hydropower stations in western China are only about 30 percent. China has a long history of manufacturing small and mini-hydro turbines. Capital costs are lower than the larger units, approximately \$850/kW (Battelle Memorial Institute, 1998).

There are substantial barriers to exploiting hydropower capacity, however. Most large sites are far from the major load centers in the coastal provinces, necessitating expensive long-distance transmission over rugged mountainous terrain. China's major rivers are heavily laden with silt from accelerated erosion. Dam projects are increasingly expensive and difficult to build, due to serious ecological and resettlement impacts. Moreover, lead times for projects are much longer than for other types of power projects, with the possible exception of nuclear power plants. On the other hand, most dam projects are multipurpose, and benefits such as irrigation, flood control, and navigation need to be considered along with power output.

C. WIND POWER

Overview

After hydropower, wind power is likely to play the most significant role in clean power generation over the coming decades in some regions of China, where emissions from coal combustion cause significant economic and environmental damage. China has been developing its wind resources for over a decade and had about 300 MW of installed capacity by mid-1999. Plans call for expansion to 3 GW in 2010 and over 8 GW in 2020 (Vaupen, 1998; World Bank, 1996).

Approximately 250 GW of exploitable wind resources exist, with world-class winds along the southeastern coastal provinces of Guangdong and Fujian and excellent wind sources in parts of Inner Mongolia, Xinjiang, Shandong, Liaoning, and Zhejiang. The greenhouse gas mitigation potential is significant. If China develops 20 percent of its wind resources (50 GW), it could generate over 130 billion kWh of power each year, displacing the need for 60 Mt of coal and the accompanying 1 Mt of sulfur dioxide and 30 Mt of carbon emissions.

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[11] Typical costs for convention coal-fired power plants in China (with particulate removal equipment but without sulfur dioxide removal equipment) are \$600 to \$700/kW. Dry and wet flue gas desulfurization technology would add about \$100/kW and \$150/kW, respectively, to plant cost (Battelle Memorial Institute, 1998).

[12] This figure is based on an estimated total project cost of \$29 billion, as reported by Steven Mufson, "Yangtze Dam: Feat or Folly," *Washington Post*, 9 November 1997. This may, however, be a large understatement of final project costs.

Technical and commercial barriers, however, restrain expansion. Power costs for wind systems are still relatively high, and technical problems need to be solved before wind can contribute more significantly to China's power mix. If China learns to manufacture large, high-quality wind turbines domestically, it could lower costs compared to the units it currently imports. Most imported wind turbines currently rely on concessional financing, but these subsidies may actually slow development of a sustainable market for wind power. On the other side, new financial and regulatory incentives, such as tax breaks and competitive bidding for new projects, could accelerate the development of a market for wind power in China.

Rural and Grid-Connected Wind Power

China's wind development efforts can be divided into two classes: rural (off-grid or household) and grid-connected. Some regions in China already have well-developed rural wind energy programs that play an important role in improving the quality of life for hundreds of thousands of Chinese living in remote areas. It is the latter, however, that has the potential to significantly affect environmental quality.

RURAL WIND POWER

Rural populations need power to raise their standard of living, but extending power grids into remote locations is expensive. Some provinces, notably Inner Mongolia, have established strong rural electrification programs using off-grid, 50 to 300 W turbines that can provide power at prices competitive with alternatives such as diesel generators (Byrne, *et al*., 1998). China is the world's largest manufacturer of small turbines, and total installed capacity now exceeds 20 MW (ALGAS). These small wind turbines are sometimes combined with photovoltaic panels to form hybrid systems that provide reliable power over a greater percentage of the year.

GRID-CONNECTED WIND

While off-grid wind power provides clean, relatively cheap power to herders, farmers, and villagers, the total impact of these units on China's environment is small compared to what grid-connected wind farms can achieve. Typical turbine units in many countries range in size from 500 to 1,500 kW, and are clustered in farms containing dozens or hundreds of units, approximating the output of a small fossil-fuel plant. The remainder of this section focuses on grid-connected wind systems in China.

Economic and Technical Issues

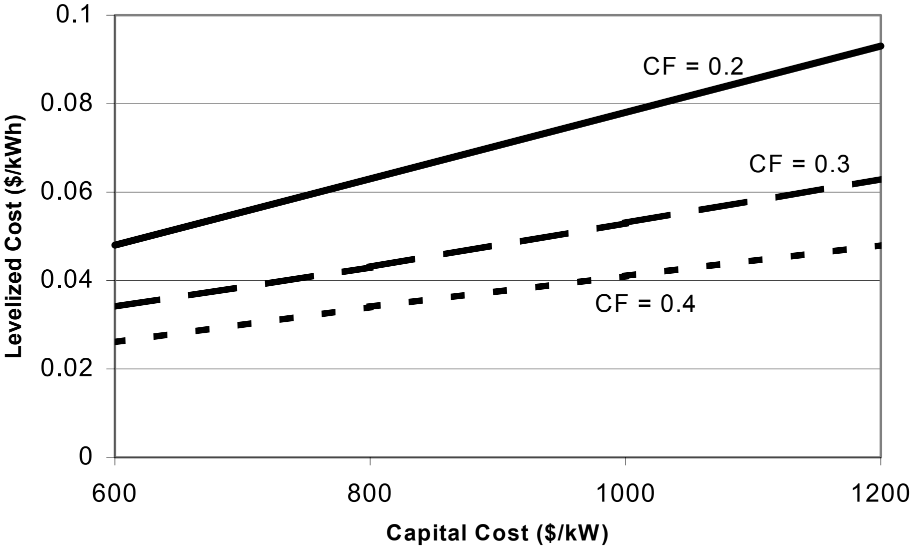
Capital costs, currently around $1,000 per kilowatt or less, are dropping rapidly. Large wind farms in developed countries may soon cost as little as $750 per kilowatt and have levelized costs below $0.05 per kilowatt-hour. Capital costs for imported wind turbines have fallen dramatically over the past decade. However, wind-generated power cannot compete on cost with fossil-fuel power in most regions of China. China is trying to develop its own wind turbine technology, both to ensure self-sufficiency and to further cut capital costs, with some success. Labor costs in China are considerably lower than in industrialized countries, so "localizing" the production of wind turbines could result in units that are 10 to 40 percent less costly than imports.

China is a world leader in manufacturing micro and small wind turbines (100 to 3,000 W), but it did not attempt to produce large units (100 kW and above) until a decade ago. Several companies in China produce 200 to 300-kW wind turbines, either as joint ventures or under license to foreign companies. Only about 10 percent of the components in these turbines need to be imported. Demand for these is low because imported 600 and 750-kW units are more cost-effective and have a reputation for higher quality (Shi, 1999).

Other companies in China also manufacture 600 kW machines, but over half of the components must be imported. The proportion of imported components will decline as companies learn to manufacture them within China, but improving quality is still a challenge. Joint-venture companies are also preparing to manufacture larger units.

The capital cost of wind turbines accounts for a significant portion of the final cost of generating power, as there are no fuel costs and taxes and operation and maintenance account for the rest. Equally important in the cost calculus, however, is the capacity factor, a measure of the amount of power generated compared to how much could have been produced if the unit operated at full capacity. Figure 3 shows that the cost of generation drops dramatically as capacity factor rises. Typical wind farms have capacity factors ranging from 0.2 to 0.4, compared to 0.5 to 0.7 for thermal power plants. Better siting or energy storage systems can raise capacity factors and improve reliability, and might dictate future penetration of wind technologies (Lew, *et al.*).

Figure 3 - Wind Power Costs in China in 1999 as a Function of Capital Cost and Capacity Factor (CF)

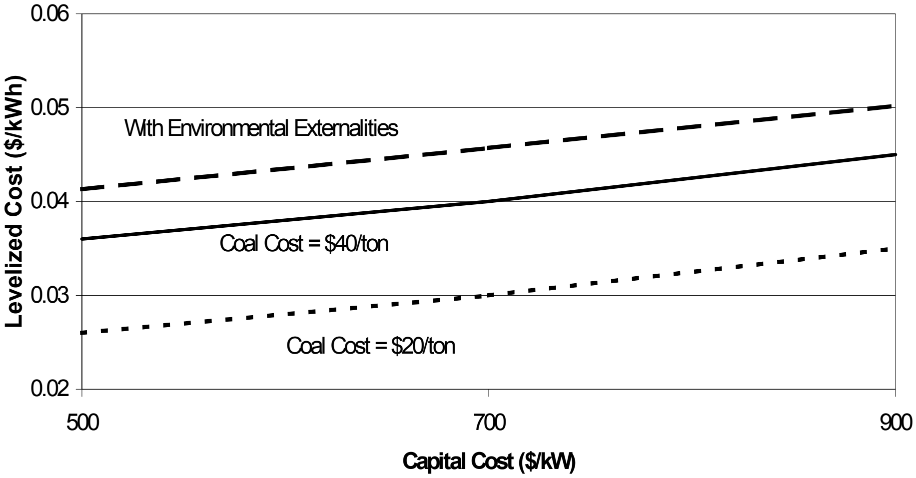


Source: Battelle Memorial Institute

In northern China, where utilities pay approximately $20 per ton for coal, the levelized cost of wind power is about 50 percent greater than coal-fired power (Figure 4). In the south, where coal prices can be twice as high, wind power is more competitive. If the health and environmental damages due to sulfur and particulate emissions are included in the cost of coal-fired power, wind is even more competitive.

Some areas of China face technical problems in integrating wind farms into local power grids, especially if the wind farm capacity is large compared to the local grid capacity. Technical training and application of software analysis tools can help solve these problems.

Figure 4 - Cost of Coal-fired Power Generation in China in 1999 as a Function of Capital and Coal Costs



Note: Environmental externalities include $500 per ton of sulfur dioxide and $1000 per ton of particulate emissions. High efficiency particulate removal is assumed.

Source: Battelle Memorial Institute

Wind Markets

Chinese utilities installed 58 MW of wind power capacity in 1998, raising the total to 224 MW. This capacity displaces coal-fired power plants that would consume approximately 250,000 t of coal and produce over 4,000 t of sulfur dioxide and 140,000 tC of carbon dioxide emissions each year. Another 100 MW were in the process of being installed for 1999, and the Chinese government plan calls for 1,500 to 2,000 MW of installed capacity by 2005.

The central government has established several important policies to promote the development of wind power. Most notably, the grid administration must allow nearest interconnection and purchase all interconnected power generation by renewable energy on a cost-plus basis. Additionally, China reduced the import duty for wind turbines in 1996 from 12 to 6 percent.

However, China's wind market has developed more slowly than anticipated, largely due to a lack of incentives for wind developers. Barriers preventing a more robust market for wind power in China include:

- scarcity of data for wind resource assessments;
- lack of local manufacturing capacity for large, high-quality wind turbines;
- slow approval of new wind farm projects;
- lack of transparency;
- difficulty in negotiating power purchase agreements;
- limited demand for new power capacity in many regions due to oversupplied markets;
- failure to account for the environmental (and economic) benefits from wind power;
- lack of incentives to reduce cost-plus pricing of wind power; and
- subsidized financing for imported wind turbines, which may delay emergence of a commercial market.

Capital for infrastructure projects such as wind farms is often limited in China, but Danish, Dutch, German, Spanish, and American turbine manufacturers often provide concessional loans to gain access to the Chinese market. These soft loans help the Chinese wind sector in the short run by allowing for technology transfer. Over the long run, however, they stifle the development of a sustainable commercial market because wind installations are limited to those that obtain concessional finance. This concessional financing will not be available forever. China may need to provide additional incentives if it wants to accelerate development of its wind sector, at least until large, high-quality turbines are produced domestically.

In addition to distorting the market and limiting development of wind power, subsidies reduce competition and encourage high capital costs. In order to resolve this issue, the World Bank and Global Environmental Facility began a project in 1998 to promote commercialization of wind energy in China through competitive bids for five wind farms.[13] The Bank hopes this project will establish clear and consistent guidelines for power purchase agreements and foreign investment. Build-operate-transfer (BOT) financing mechanisms, in particular, have the potential to reduce costs by introducing competition.

Comparative Policies

Several Chinese provinces have begun to offer fiscal incentives to developers of wind power. For example, Guangdong and Jilin have reduced value-added and income taxes on wind-generated electricity (Vaupen, 1998). Despite these efforts, both domestic and foreign wind developers need greater incentives to accelerate the development of China’s wind market.

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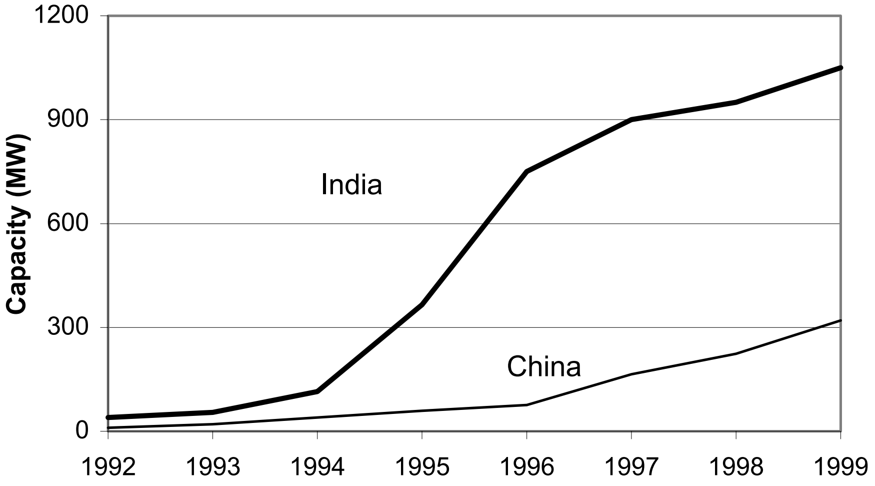
[13] Project loan financing of US$100 million and a Global Environment Facility grant of US$35 million will finance the wind power activities in Inner Mongolia, Hebei, Fujian, and Shanghai, as well as a project to provide households and businesses with standalone photovoltaic systems in northwestern China (Asian Energy News, 1999).

Figure 5 - Wind Power in India and China, Installed Capacity



Source: Tata Energy Research Institute and Shi Pengfei.

Wind power has expanded significantly over the past five years in India (Figure 5), and that experience provides an interesting example of incentives that can accelerate business activities. Rather than impose development targets, financial incentives, such as tax rebates on investment, drive demand in India. Banking and foreign exchange reforms have also improved the competitive position of wind power by generating significant “demand pull” for wind power by the private sector (Shukla, *et al.*). Market dynamics have also aided technology transfer. Foreign wind-technology companies competed to supply technology, and Indian companies formed joint ventures with wind technology suppliers. Implementation experience has lowered the costs of wind power, whereas enhanced manufacturing and servicing capacity has lowered the risk.

The Indian experience has not occurred without problems, however. Initially, tax credits were offered simply for installing new wind capacity without any link to power production. Policymakers in India recently revised the financial incentives to promote actual electricity generation from wind farms.

D. BIOMASS

From the 1950s to the 1970s, households in rural areas have met their increasing needs for fuel through over-consumption of biomass resources, including firewood, crop wastes, grasses, and dung. The results were serious deterioration in soil fertility and other environmental impacts (Yang and Fridley, 1996). However, with rapid economic growth since the early 1980s, fossil fuels and electricity have replaced much biomass energy. By 1992, rural industry depended on biomass for under 44 percent of total energy use, while the corresponding share for households remained high at about 70 percent. (See Table28.) China currently uses about 240, 180 and 9 million tons of straw, firewood and animal wastes, respectively, as energy fuels (about 7.6 EJ) each year in rural areas.

Table 28 - Rural Energy Consumption by Sector, TJ, 1979, 1992

	1979			1992		
Energy Types	**Total**	**Industry & Agriculture**	**Households**	**Total**	**Industry & Agriculture**	**Households**
Straw	3,333	-	3,333	3,972	-	3,972
Dung	185	-	185	410	-	-
Fire wood	3,042	-	3,042	3,233	492	2,740
Electricity	487	396	91	1,559	1,231	328
Petroleum Products	416	375	44	950	909	41
Coal	1,706	750	956	6,990	4,678	2,313
Total	9,168	1,518	7,650	16,701	7,310	9,394

Source: *Rural Energy Planning,* edited by Xichun Xu *et al*., Chinese Statistical Publishing, Beijing, 1990, and *China Energy Annual Review, 1994,* SETC, 1994.

Since 1979, major efforts have been aimed at increasing the efficiency of biomass fuel use and making fuelwood more available, as well as increasing the availability of non-biomass energy. Good examples are the well-funded program aimed at introducing improved biomass cooking stoves into rural households and large-scale, multi-use afforestation projects. The improved biomass cookstoves raise the efficiency of biomass use from 10 percent to 20 percent in traditional stoves to about 25 percent. Other programs have promoted biomass gasification (at household, village and industrial scales), allowing further increases in stove efficiency, to about 45 percent. Similar energy-efficiency benefits are associated with shaped biomass waste, a fuel form that can be easily distributed like commercial energy forms (Yang and Fridley, 1996).

In the 1970s, China began a campaign to introduce household- and village-scale biogas digesters throughout China. Unfortunately, the campaign was characterized by more enthusiasm than technical soundness, and most of the digesters quickly fell into disuse. In the 1980s, a program with more modest aims, but armed with lessons learned from earlier failures, was begun, with a focus on larger-scale projects, including industrial-scale biogas cogeneration projects at sugar and forest-product processing plants.

Biomass can be used to generate power either by direct combustion or gasification. Direct-combustion systems operate like coal-fired units, using steam turbines to produce electricity. In developed nations, most biomass plants are combined heat and power systems. Designs are moving away from simple grate systems to fluidized bed and circulating bed systems that can handle a wide range of feedstock quality, and gasification systems. The latter, now being commercialized, do not need to rely on large units to achieve economies of scale. China could rapidly develop key biomass technologies that could double conversion efficiencies and make biomass an attractive source of energy for both industry and utilities in rural areas (Battelle Memorial Institute, 1998).

Development of biomass energy will be limited not just by competition from other energy sources, which will limit applications to niche markets, but by competing uses for biomass. In many parts of China, a variety of ills are attributable to unsustainable harvesting of trees, crop residues, and other vegetation. Sustainable use of biomass requires greater care in managing biomass resources. Given this, overall use of biomass fuels in China is likely to decline. This is reflected in recent analytic work, such as the China Climate Change Country Study (RTCCCCS, 1998).

E. GEOTHERMAL ENERGY

Total high-temperature geothermal resources, defined as waters above 150ºC, are estimated at under 7 gigawatts. Most of these resources are concentrated in southern Tibet (1000 MWe exploitable potential) , and much of the remainder is in western Yunnan (570 MWe) and western Sichuan (170 MWe). While most projects have been quite small (under 300 kW), a 25 MW plant supplies a significant portion of Lhasa's power neeeds. This plant accounted for most of the 29 MW of geothermal generating capacity in China in 1995. There are abundant medium- and low-temperature geothermal resources in other parts of the country. Power generation with these resources is currently infeasible, although it has been put to other uses, e.g., space heating and industrial process heat. Development of geothermal power will likely continue in this region as a niche application, with plans calling for 210-295 MWe by 2010 and 400-590 MWe by 2020 (Battelle Memorial Institute *et al*., 1998; Sinton *et al*., 1996; EIA, 1997; IGA, 1997).

F. SOLAR TECHNOLOGIES

Direct Uses of Solar Energy[14]

With average annual solar radiation of 5.9 x 10^6 kJ/m^2-yr (1,640 kWh/m^2-yr), China has considerable potential for using solar energy. China has given solar energy technologies attention mainly as an element in rural development.

At the end of 1994, there were over 2.9 million m^2 of solar water heaters, each providing energy services of 2900 to 4400 MJ/yr, and collectively providing the equivalent of 8.5 to 13 TJ/yr. There were already 300 manufacturers of solar water heaters, manufacturing flat-plate, evacuated-tube, and integrated heaters. The potential demand in newly constructed housing for solar water heaters was about 0.9 million m^2 in rural areas and 1.5 to 2.0 million m^2 in cities. It was projected that there would be over 10 million m^2 of solar water heaters in operation by 2000, avoiding 0.7 MtC of carbon dioxide emissions.

Houses with passive solar design (mainly in northern and western China) totaled 2.6 million m^2 at the end of 1994, saving 600 to 1200 MJ/m^2 in winter. It was estimated that by 2000 there would be 50 million m^2 of floor space in passive solar houses, replacing 44 TJ/yr in coal for household stoves, and thus avoiding carbon dioxide emissions of 1.1 MtC.

In 1994, solar greenhouses had a total area of 215 million m^2. Solar cookers were widely available to rural households, with 1.45 million units deployed, each replacing 500 to 700 kg of biomass annually. Also installed were 12,000 m^2 of solar dryers.

Photovoltaics

China started research and manufacturing of solar photovoltaic (PV) cells, which convert sunlight directly into electricity, in 1958. Before the early 1980s, development concentrated on units up to a few dozen watts. In the past decade, China had imported seven PV manufacturing lines from the US, Canada and other countries, and current total production

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[14] This section is based on Yang and Fridley, 1996, The World Bank, 1996, and RTCCCCS, 1999.

capacity is over 4.5 MW per year. A number of universities, research institutes and factories are involved in R & D, manufacturing and application (Yang and Fridley, 1996).

Costs are dropping rapidly from the current level of near $4,500/kW. Multinational oil companies such as British Petroleum and Shell have invested in PV production facilities. New thin-film PV cells will have lower costs, greater efficiency, and longer life than conventional silicon-based cells, and are a priority research topic for Chinese scientists (Battelle Memorial Institute).

Table 29 - Prospects for China's Solar PV Market

Period	Production Capacity (MW)	Cell Price (1989 yuan/peak W)	System Price (1989 yuan/peak W)	Scale
1996-2000	10-50	c-Si 15 a-Si 8	c-Si 30-50 a-Si 25-45	0.01 to 1 MW Commercial IPP
2000-2100	>100	5 – 10	4 – 20	> 1 MW Grid-Connected

Source: Renewable Energy Development in China, State Science and Technology Commission, Beijing, 1992.

About 3 MW of PV cells are currently in use in rural China (Battelle Memorial Institute). Solar PV power stations have been established in Inner Mongolia, Gansu, and Tibet. For example, three solar PV stations with installed capacity of 10, 20 and 25 kWe have been built in three counties in Tibet that have no grid connections or power stations. Solar PV has been widely used in agriculture, husbandry, transportation, telecommunications, meteorological and earthquake stations, medical, and military bases. The future market for solar PV applications is promising, as indicated in Table 29. In particular, there are 28 counties, more than 10,000 villages, and thousands of islands along the coast that currently have no access to electricity (Yang and Fridley, 1996).

G. TIDAL AND OCEAN ENERGY

Although some experimental tidal power stations have been built in China, the total installed capacity is under 10 MW. Since the resources are relatively small and capital costs higher than for other renewable energy sources, such as small hydropower and wind, significant development of this resource is unlikely to occur soon (Sinton *et al.*, 1996).

H. FUEL CELLS[15]

Fuel cells are fundamentally different from other power systems because they produce electricity as well as useable heat, through chemical reactions without combustion. The technology is a clean, quiet, and efficient method of producing power and heat from a variety of fuels. Natural gas is the most common fuel used today, but coal gas, methane, biogas, alcohols, and hydrogen can also be used.

In developed countries, rapid advances in fuel cell technology may soon revolutionize electric power generation, personal transportation, and heat and power production for

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[15] This section is based on Battelle Memorial Institute, *et al.*, 1998.

buildings. Competitively priced electricity from fuel cell plants operating at nearly twice the efficiency of present-day coal technologies may begin entering markets in North America, Japan and Europe by the early years of the new century. Fuel-cell vehicles, offering performance, cost and safety equivalent to today's internal combustion engine vehicles, but with dramatically reduced pollution and noise, could be widely available in a decade. For China, fuel cell applications in the transportation sector could have a greater economic and environmental impact than power sector applications.

Fuel cells promise higher fuel efficiency than today's technologies relying on combustion. For China, they could thus help reduce petroleum imports and enhance energy security. Fuel cells also offer local environmental benefits, including significant reductions of emissions of sulfur oxides, particulates, hydrocarbons, and noise.

Recent scientific advances and technical demonstration efforts have brought fuel cells closer to commercialization in a wide variety of stationary and mobile applications. Key issues for their market acceptance are cost and infrastructure. Overall cost is much less a matter of the cost of producing hydrogen than the capital cost of the fuel cells themselves and the transport and storage of the hydrogen fuel.

I. POLICY AND INSTITUTIONS

Policy

China has long advocated renewable energy in its policy documents and plans, both for the energy sector and rural development. Most recently, in January 1999, the State Development Planning Commission (SDPC) and the Ministry of Science and Technology (MST) issued a policy directive aimed at supporting the development of renewable energy (SDPC and MST, 1999). The major points of the directive included the following:

- The government will provide planning and financial support renewable energy projects.
- Power projects using renewable energy resources will be given priority in approval of loans from the State Developing Bank. The state will aid qualified developers of projects over 3 MW obtain commercial loans, and buy down the interest on such loans by two percentage points.
- Priority will be given to projects that use Chinese-made equipment, and loan repayment periods may be extended.
- Grid management utilities should purchase the power output of qualified renewable power projects.
- Power pricing for renewable power projects should enable cost recover plus profit. In the case of projects using imported equipment, the profit rate should be under 3 percent, and for those using domestic equipment the rate should be at least 5 percent.

To date, no projects have gone forward under this policy. The major sticking point seems to be lack of clarity on how the additional higher cost electricity from renewables projects is to be allocated among customers of the grid that purchases the electricity (Lew, 1999).

Finance and Investment

Financing of wind energy projects has been heavily dependent on foreign aid, a dependency that has grown stronger (Lew, 1999). The Danish government, for instance, in 1998 committed to a $150 million aid package over three years for wind generators, a deal that made money for a similar $135 million World Bank project for renewables projects (wind farms and off-grid PV systems) less attractive. As Lew (1998) notes:

> "It is estimated that 90 percent of wind power installations were funded through concessional financing. While capital may be limited in China, the willingness of foreign governments to give subsidized loans for the capital cost of wind turbines has eroded the Chinese willingness to pay full cost. The availability of concessional finance has led to…only as much development as could be funded by these subsidies."

Most off-grid, household wind systems installed to date in China have been purchased with cash, as credit financing is not widely used in much of rural China (Lew, 1998).

In general, current conditions in China are not conducive to investment in power generation. In 1998, the rate of growth in power generation fell considerably below that of the economy, and many regions are experiencing excess capacity.[16] The situation for renewables, however, may not be as bleak. While the government has put a three-year moratorium on construction of new conventional power plants, opportunities remain open for investment in renewable power sources, providing an outlet for generating utilities for continuing investment (Lew, 1999).

On the other hand, renewables will have difficulty competing on a cost basis with conventional forms of generation. As a Resources for the Future study on the U.S. showed, although costs of generation for the main renewable energy technologies fell even faster than projected, costs of conventional power generation fell also even as environmental performance improved, leading to market penetration considerably less than projected (Burtraw, *et al.*, 1999). The same may apply in China, although currently even China's newer, more-efficient conventional power plants are not being fully utilized, as utilities preferentially dispatch older, less-efficient plants that are fully depreciated and locked into low price agreements (Heller, 1999).

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