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China
Efficiency and Environmental Impact of Coal Use

(In Two Volumes) Volume II: Annexes

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CURRENCY EQUIVALENTS

Currency	-	Renminbi (RMB)
Currency Unit	-	1 Yuan (Y) = 100 fen

Average exchange rate:	1983	1985	1986	1987	1989
Y/US$	1.9	2.94	3.45	3.72	4.7

FISCAL YEAR

January 1 to December 31

WEIGHTS, MEASURES AND CONVERSION FACTORS

kcal	=	4.1868 kilojoules = 3.968 Btu
Gcal	=	10^6 kcal
km	=	0.621 mile
kWh	=	859.8 Kcal
kilogram	=	2.21 pounds
metric ton (t)	=	1,000 kg
MJ	=	1,000 kilojoules or 239 Kcal
GJ	=	1 million kilojoules
tce (ton of coal equivalent)	=	1,000 kg with 6,680 kcal per kg or 6.7 million kcal
1 ton of coal (run-of-mine average)	=	5.0 million kilocalories
toe (ton of oil equivalent)	=	10.2 million kilocalories
1,000 cubic meters of natural gas	=	9.31 million kilocalories

PRINCIPAL ACRONYMS AND ABBREVIATIONS

AIC - Average incremental cost, a proxy for LRMC
BAP - *Benzo-a-pyrene (trace aromatic hydrocarbon)*
CHP - Combined heat and power
C - Carbon
CFBC - Circulating fluidized bed combustion
CGCC - Coal gas combined cycle
CO - Carbon monoxide
CO_2 - Carbon dioxide
CPE - Centrally planned economy
CUDC - China General Coal Utilization and Development Corporation
CWM - Coal water mixture (or CWS)
CWS - Coal water slurry
DH - District heating
EPB - Environmental protection bureaus (provincial or municipal level)
ERI - Energy Research Institute, SPC
ESP - Electrostatic precipitator
FBC - Fluidized bed combustion
FGD - Flue gas desulfurization
gce - grams of coal equivalent
GDP - Gross domestic product
GJ - Gigajoules
GWh - Gigawatt hours
IEA - International Energy Agency
kg - Kilograms
kgce - kilograms of coal equivalent
kW - Kilowatts (capacity)
kWh - Kilowatt hours
LPG - liquefied petroleum gas
LRMC - long run marginal cost
M - million
m - meter
mm - millimeter
m^2 - square meters
m^3 - cubic meters
MJ - megajoules
MMEI - Ministry of Machinery and Electronics Industries
MMI - Ministry of the Metallurgical Industry
MOE - Ministry of Energy
Mtpy - million tons per year
MW - Megawatts
NEPA - Chinese National Environmental Protection Agency
NM^3 - Normal cubic meter
NO_2 - Nitrogen dioxide
NO_3 - Nitrate
NO_x - Nitrogen oxide
OECD - Organization for Economic Cooperation and Development
PAH - Polyaromatic hydrocarbons
PCF - Pulverized coal-fired (boiler)
PCI - Pulverized coal injection
pH - degree of acidity
ROM - run-of-mine
stph - tons of steam per hour
S - Sulfur
SO_2 - Sulfur dioxide
SO_4 - Sulfate
SO_x - Sulfur oxide
SPC - State Planning Commission
SSTC - State Science and Technology Commission
t - ton (metric)
tce - tons of coal equivalent
tkm - ton-kilometer
toe - tons of oil equivalent
tpa - tons per annum
TSP - Total suspended particles
TVEs - Township and village enterprises
$\mu g/m^3$ - micrograms per cubic meter
WHO - World Health Organization

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Foreword

This study was undertaken as a collaborative effort with three Chinese institutions: the China General Coal Utilization and Development Corporation (CUDC), lead institution; the Energy Research Institute (ERI) under the State Planning Commission (SPC); and the China Environmental Strategy Research Center under the National Environmental Protection Agency (NEPA). Special thanks go to Messrs. Li Zhongqi and Gui Kai, CUDC; Zhou Fengqi, ERI; and Zhang Chonghua, NEPA.

The Chinese counterpart team prepared working papers for the study and organized site visits during the main study mission. The authors of the working papers are as follows: Working papers #1 (Coal Resources and Environmental Impact of Coal Utilization) and #4 (Coking Coal): Li Xuesheng, Hao Yuyong, Jia Qinxou and Xie Jianning; Working paper #2 (Domestic and Commercial Coal Use): Song Wucheng, Liu Zhiping, Liu Xueyi, Zhang Ying, Zhang Tingwu, and Xin Guirong; Working paper #3 (Industrial Coal Use): Xin Dingguo, Hu Xiutian, Bai Rongchun, Chen Min; Working paper #5 (Electric Power Sector): Zhi Luchuan, Chu Ming, Han Yinghua, Chen Kai; Working paper #6 (Coal Gas and District Heating): Liu Wen, Wang Yanxiang.

The Bank report and its annexes were prepared by K. Stephenson (task manager) based on missions in April and October 1989 and individual analyses by the following consultants: B. Adamson, University of Lund (building insulation); A. Christensen, CowiConsult (district heating); H. Falkenberry, power engineer (boiler technology); A. Gibson, Coal Processing Consultants (briquetting); D. James, Ecoservices Pty. Ltd. (industry and environment); D. Prior, energy economist (household energy); D. Simbeck, SFA Pacific Inc. (coal gasification, steel and ammonia industries); and D. Symonds, NorWest Resource Consultants (coal washing). In addition, the Coal Research Establishment (British Coal) calculated estimates of emissions from different coals and briquettes used in Chinese households. Y. Albouy (AS3IE) contributed substantially to the sections on the electric power industry and district heating and also provided very useful general comments. S. Chattopadhya (ASTEG) and C. Warren (IFC) contributed to the sections on coal mining and coal pricing respectively. H. Yen and Y.J. Zhao provided research assistance. Very helpful comments were received from several Bank staff members: R.P. Taylor, R. Batstone, K. Constant, and M. Fog. W. Spofford of Resources for the Future also provided useful comments on environmental issues.

The members of the Bank team would like to acknowledge the invaluable support given by their Chinese colleagues in conducting this study, including organizing and leading extensive visits and discussions with experts in various cities in China. Without them, this report would not have been possible.

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Glossary of Technical Terms 1/

Acid Deposition	Precipitation which is lower in pH than normal rain water and dry fallout of potentially acidifying salts.
Average Incremental Cost	A proxy for long-run marginal cost, it is calculated as follows: A/B, where A = Present value of total capital and cash operating costs (discount rate = 10 percent); B = Total annual production over project life, discounted by 10 percent.2/
Bottom Ash	Ash derived from fossil fuel combustion which is melted and removed generally in a water stream at the bottom of the boiler.
Coal Gasification	The process of converting coal into a combustible gas. Various technologies exist, from the original gas producer, operating at atmospheric pressure, to modern, pressurized oxygen-blown gasification processes which are state-of-the-art today. Coke ovens also produce gas from coal as a by-product.
Cogeneration Facility	Plant designed to produce both electric power and steam for industrial or commercial purposes.
Electrostatic Precipitator (ESP)	A process for particulate removal from flue gas derived from fossil fuel combustion by electrostatic attraction. Particles in the gas stream become electrically charged and adhere electrostatically to a large metal plate. The most common ESP is the so-called "cold-side" design, although "hot-side" units are also in operation particularly with very low sulfur fuels.

1/ Many of these definitions come from: International Energy Agency. Coal Use and the Environment Report by the Coal Ind. Advisory Bd. OECD, vol. I, March 1983, pp. B1-B4.

2/ In other words, a present value for production volume is calculated.

Fabric Filters	A process for particulate removal from flue gas by filtering the gas stream through closed cylindrical fabric bags assembled in what are known as "bag houses." Fiberglass is often the fabric of choice.
Flue Gas Desulfurization (FGD)	The process of removing sulfur dioxide from gas derived from fossil fuel combustion. SO_2 scrubber is the common term for FGD equipment.
Fluidized Bed Combustion (FBC)	The process of combustion in a bed of inert particles fluidized by air. There are two types of FBC--bubbling and circulating. Operation can take place at atmospheric or elevated pressure (the latter is state-of-the-art technology).
Fly Ash	Ash derived from fossil fuel combustion which is carried out of the boiler in the flue gas.
Micron	One-millionth of a meter (a common measurement of particulate diameter).
Pulverized Coal-Fired Boiler (PCF)	A boiler which utilizes finely ground coal as its predominant fuel. Usually high performance utility boilers are PCF boilers.
Regenerable FGD	FGD process which does not produce a significant by-product waste stream. Predominant products are sulfur or sulfuric acid. It involves higher investment and operating costs.
Scrubber Sludge	The waste product produced by nonregenerable flue gas desulfurization. (It can be oxidized to produce gypsum.)
Stoker-Fired Boiler	A boiler employing lump coal placed on a traveling or stationary grate.
TSP	Total suspended particles, which are particulates of coal, ash and trace elements which escape the flue stack of a boiler after combustion.

Chinese Coal Characteristics and Terminology 3/

1. According to the classification theme used in China, there are ten main types of coal produced, each with specific characteristics and suitable uses. These types are:

(a) Lignite
(b) Bituminous flame coal }
(c) Noncaking coal }
(d) Weakly caking coal } Bituminous steam coals
(e) Lean coal }
(f) Gas coal }
(g) Fat coal }
(h) Coking coal } Coking coals
(i) Blackjack }
(j) Anthracite

The characteristics and uses of the four main groupings of coals are given below.

Lignite

2. This coal is characterized by low heat content (3,000-4,000 kcal/kg), high moisture content (15-40 percent) and high volatiles content (37-60 percent). The few lignite mines in Jilin, Henan and Shendong have relatively high heat contents, above 4,000-5,000 kcal/kg. Ash contents are generally 20-30 percent, although some lignite mines in Inner Mongolia, Jilin and Yunnan have ash contents below 15 percent. Sulfur content varies from below 0.5 percent to over 6 percent. Sulfur content of northeast lignites is generally below 1 percent, while that of Guangdong, Guangxi and Hainan Island lignites is 1.5-2.5 percent. Given the high transport cost per unit heat of lignite, lignites are used mostly for minemouth power generation.

Bituminous Steam Coals

3. This group comprises flame coal, noncaking coal, mostly weakly caking coals and lean coal (types b,c,d and e). The common characteristic of this group of coals is that they do not have caking characteristics or are only very weakly caking. The main characteristics of these coals are summarized below:

Table 1: CHARACTERISTICS OF BITUMINOUS COALS

Type of coal	Volatiles content (%)	Moisture content (%)	Heat content (kcal/kg)	Ash content (%)	Sulfur content (%)	Main producing areas and mines
Flame	37-47	8-16	3,500-6,000	7-20	0.5-1.3	Northeast (Fuxin, Fushun Xilutian (Tiefa)
Noncaking	25-35	4-12	5,500-6,400	6-16	0.8	Inner Mongolia, Northeast
Weakly caking	24-34	2-10	5,300-6,800	5-22	0.3-1.5	Datong, Sishuayuan, Fangzi, Zhengyang, Zhangxin, Baotou
Lean	10-20	3-6	5,500-6,800	8-30	0.6-4.0	Zibo, Xishan

3/ Source: China Coal Pricing Study, Annex 1, February 1989.

4. Production of noncaking coal is low, despite abundant reserves. Weakly caking coals are produced in large quantities, the Datong mines being the largest single source. Flame coal is used as a power plant fuel, for firing cement in rotary kilns, for locomotives and the manufacture of coal gas and synthetic gas. Lump flame coal with high tar content can be used to produce tar and half coke, which is used as a civilian fuel. Noncaking coals are used in the same applications as flame coals and, in addition, for the manufacture of activated carbon. Weakly caking coal is a good quality coal for power generation and locomotive use, due to its high calorific value. Weakly caking coal with low ash and sulfur content and good caking characteristics is blended with prime coking coal to produce metallurgical coke.

5. Lean coal is a prime fuel for thermal power generation and, in lump form, can be used as a civil fuel. The higher ash and sulfur varieties are also used in the manufacture of synthetic ammonia, and the lower ash and sulfur varieties for blast furnace blowing or sintering of iron.

Bituminous Coking Coals

6. This group comprises gas coal, fat coal, coking coal and blackjack (types f, g, h and i). Their common characteristic is a relatively strong caking quality, though the strength of coke produced by the different types differs markedly.

7. Reserves of gas coal are the most abundant and production is the highest of all types of coal, with a large proportion in east China. Gas coal is subdivided into fat gas coal (two grades), with better caking characteristics and volatiles content between 30 and 37 percent, and gas coal (three grades), with 37 to 45 percent volatiles. Fat gas coal is the principal coking coal used in China's coking plants; sulfur content is generally below 1 percent. Coke produced by gas coal grades 2 and 3 is not strong and these coals are generally blended with others for coking purposes.

8. Fat coal has the strongest caking characteristics and a volatiles content between 24 and 45 percent, with an inverse relationship between volatiles content and coke characteristics. Sulfur contents are high, with many fat coals above 2 percent and some over 5 percent. Reserves of fat coal are scarce and it is blended with other coking coals to produce coke.

9. Coking coal, with volatiles content between 20 and 30 percent, has the best coking characteristics, and when used by itself produces very strong metallurgical coke. Thermal value is high (up to 8,900 kcal/kg for the pure coal) and sulfur content generally below 1 percent. Mines producing coking coal include Fengfeng, Huaibei, Qitaihe, Jixi and Hunan mines. Blackjack is a low volatile coking coal (14 to 20 percent) with poor caking characteristics used as a blending coal to give strength to the coke. Sulfur content tends to be high; consequently, the proportion of blackjack used for coking is small.

Anthracite

10. Anthracite is characterized by high density, high ignition temperature (370 to 418°C), low volatiles content and a calorific value generally ranging from 4,800 to 7,500 kcal/kg. Ash content ranges from 4 to 30 percent.

Mines producing anthracite include Yangquan, Chengzhuang, Jiaozuo, Beijing, Jincheng and Rujiguo. Main uses of anthracite are gasification for synthetic ammonia manufacture, as a reducing agent in iron smelting in small blast furnaces and as a household fuel. Anthracite fines are used in large quantities to manufacture honeycomb briquettes for household use. Low ash, low sulfur anthracite (e.g., from the Jixi mine) is used in the manufacture of carbon electrodes and other high grade carbon materials and also is exported.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Environmental Standards

Table 1: AMBIENT AIR QUALITY STANDARDS IN CHINA

Pollutant	Time period	Ambient standard ($\mu g/m^3$) Class I	Class II	Class III
Total suspended particulates (TSP)	Daily average	150	300	500
	Maximum at any time	300	1,000	1,500
Particulates (<10 microns)	Daily average	50	150	250
	Maximum at any time	150	500	700
SO_2	Annual daily average	20	60	100
	Daily average	50	150	250
	Maximum at any time	150	500	700
NO_x	Daily average	50	100	150
	Maximum at any time	100	150	300
CO	Daily average	4,000	4,000	6,000
	Maximum at any time	10,000	10,000	20,000
Photochemical oxidant (O_x)	Hourly average	120	160	200

Source: Environmental Protection Office, Working Group on Standards (1982).

Table 2: DATA ON AMBIENT CONCENTRATIONS IN CHINESE CITIES
(Ambient concentrations of TSP and SO_2 in 1988)
($\mu g/m^3$)

City	Monitoring station	TSP Annual average	TSP Maximum	SO_2 Annual average	SO_2 Maximum
Beijing	1	473	930	123	332
	2	504	853	249	566
	3	321	610	73	246
	4	493	965	219	490
Guangzhou	1	118	557	7	26
	2	227	572	93	178
	3	150	456	43	151
	4	325	640	143	342
Shanghai	1	303	854	34	206
	2	360	765	115	238
	3	215	388	95	176
	4	192	519	13	50
Shenyang	1	598	1,531	115	313
	2	593	1,546	200	623
	3	540	1,260	213	550
	4	304	760	78	456
Xian	1	495	1,102	124	140
	2	617	1,263	158	289
	3	708	1,310	170	317
	4	625	1,195	145	198

Source: WHO, Global Emissions Monitoring System (GEMS).

Table 3: SHENYANG: DAILY AVERAGE, AMBIENT CONCENTRATIONS OF AIR POLLUTANTS, 1981-87 ($\mu g/m^3$)

Year	TSP	SO_2	NO_x
1981	1,023	158	94
1982	699	116	69
1983	1,142	109	68
1985	1,167	127	71
1985	608	116	75
1986	534	159	69
1987	646	143	62

Table 4: TAIYUAN: DAILY AVERAGE, AMBIENT CONCENTRATIONS OF AIR POLLUTANTS, FOURTH QUARTER 1988

Pollutant	Quarterly average ($\mu g/m^3$)	% exceedance of daily average standard
TSP	1,070	95
SO_2	250	67
NO_x	60	9
CO	2,800	19

Table 5: CHONGQING: DAILY AVERAGE, AMBIENT CONCENTRATIONS OF AIR POLLUTANTS, FOURTH QUARTER 1988

Pollutant	Quarterly average ($\mu g/m^3$)	% exceedance of daily average standard
TSP	520	72
SO_2	380	82
NO_x	80	19
CO	2,230	10

Table 6: JIANGSU PROVINCE: AMBIENT CONCENTRATIONS OF AIR POLLUTANTS, 1988
(Averaged quarterly data for four cities)
($\mu g/m^3$)

City/Town	TSP	SO_2	NO_x
Suzhou	377	98	46
Wuxi	304	166	47
Changzhou	341	74	40
Zhenjiang	619	116	50

Table 7

EMISSION STANDARDS OF 13 KINDS OF HAZARDOUS POLLUTANTS
(GBJ4-73)

表1　十三类有害物质的排放标准

No 序号	Pollutants 有害物质名称	Enterprises 排放有害物企业(1)	Emission Standards 排放标准 Height of exhaust stack (M) 排放筒高度(米)	 Emission amount (Kg/hr) 排放量(2)(公斤/小时)	 Emission Concentration (mg/M³) 排放浓度(毫克/立方米)
1	二氧化硫 SO_2	电站 Power station	30	82	
			45	170	
			60	310	
			80	650	
			100	1200	
			120	1700	
			150	2400	
		冶金 Metallurgy	30	52	
			45	91	
			60	140	
			80	230	
			100	450	
			120	670	
		化工 Chemical Industry	30	34	
			45	66	
			60	110	
			80	190	
			100	280	
2	二硫化碳 CO_2	轻工 Light Industry	20	5.1	
			40	15	
			60	30	
			80	51	
			100	76	
			120	110	

EMISSION STANDARDS OF 13 KINDS OF HAZARDOUS POLLUTANTS
(GBJ4-73)

No	Pollutants	Enterprises	Emission Standards		
			Height of exhaust stack (M)	Emission amount (Kg/hr)	Emission Concentration (mg/M3)

表1　十三类有害物质的排放标准

序号	有害物质名称	排放有害物企业①	排放标准		
			排放筒高度（米）	排放量②（公斤/小时）	排放浓度（毫克/立方米）
3	硫化氢 Hydrogen Sulphide	化工、轻工 Chemical & Light Industries	20	1.3	
			40	3.8	
			60	7.6	
			80	13	
			100	19	
			120	27	
4	氟化物（换算成F） Fluoride converted to F	化工 Chemical Industry	30	1.8	
			50	4.1	
		冶金 Metallurgy	120	24	
5	氮氧化物（换算成NO_2） NO_x converted to NO_2	化工 Chemical Industry	20	12	
			40	37	
			60	86	
			80	160	
			100	230	
6	氯 Chlorine	化工、冶金 Chemical Industry, Metallurgy	20	2.8	
			30	5.1	
			50	12	
		冶金 Metallurgy	80	27	
			100	41	

EMISSION STANDARDS OF 13 KINDS OF HAZARDOUS POLLUTANTS
(GBJ4-73)

No	Pollutants	Enterprises	Emission Standards		
			Height of exhaust stack (M)	Emission amount (Kg/hr)	Emission Concentration (mg/M^3)
序号	有害物质名称	排放有害物企业	排放标准		
			排放筒高度 (米)	排放量 (公斤/小时)	排放浓度 (毫克/立方米)
7	氯化氢 Hydrogen Chloride	化工、冶金 Chemical Industry, Metallurgy	20	1.4	
			30	2.5	
			50	5.9	
		冶金 Metallurgy	80	14	
			100	20	
8	一氧化碳 CO	化工、冶金 Chemical, Metallurgy	30	160	
			60	620	
			100	1700	
9	硫酸(雾) Sulphuric Acid (Fog)	化工 Chemical Industry	30 —45		260
			60 —80		600
10	铅 Lead		100		34
			120		47
11	汞 Mercury	轻工 Light Industry	20		0.01
			30		0.02
12	铍化物(换算成Be)	Beryllium Compound	45 —80		0.015

EMISSION STANDARDS OF 13 KINDS OF HAZARDOUS POLLUTANTS
(GBJ4-73)

No	Polutants	Enterprises	Emission Standards: Height of exhaust stack (M)	Emission Standards: Emission amount (Kg/hr)	Emission Standards: Emission Concentration (mg/M^3)
13	烟尘及生产性粉尘 Fume and Industrial Dust	电站（煤粉） Power Station (Coal-dust)	30	82	
			45	170	
			60	310	
			80	650	
			100	1200	
			120	1700	
			150	2400	
	Industrial & Heating Boilers	工业及采暖锅炉			200
	Electric-arc furnace	炼钢电炉			200
	Converter	炼钢转炉			
	Less than 12 tons	（小于12吨）			200
	Greater than 12 tons	（大于12吨）			150
	Cement	水泥			150
		生产性粉尘③			
	Industrial Dust I	（第一类）			100
	II	（第二类）			150

注：①表中未列入的企业，其有害物质的排放量可参照本表类似企业。

②表中所列数据按平原地区，大气为中性状态，点源连续排放制定，间断排放者，若每天多次[illegible]，其排放量按表中规定；若每天排放一次而又小于一小时，则二氧化硫、烟尘及生产性粉尘、[illegible]碳、氟化物、氯、氯化氢、一氧化碳等七类物质的排放量可为表中规定量的三倍。

③系指局部通风除尘后所允许的排放浓度。

第一类指：含10%以上的游离二氧化硅或石棉的粉尘、玻璃棉和矿渣棉粉尘、铝化物粉尘等

第二类指：含10%以下的游离二氧化硅的煤尘及其他粉尘。

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Coal Use and Environmental Impact on Select Cities and Provinces

Beijing

1. Coal consumption in Beijing is about 21 million tons, accounting for 70 percent of primary energy use (1988 data). Approximately 14 percent of coal is consumed by electric power stations, 27 percent by coking, 30 percent for industrial purposes, 23 percent in households and 6 percent for other uses. In 1988, there were 19,500 boilers, of which two-thirds were used for heating. There were 35,000 large stoves in restaurants, 13,000 small boilers for hot water for drinking, 2,000 industrial kilns and furnaces, and 1.5 million household stoves. About 50 percent of heating is by individual boilers or district heating; another 50 percent is by coal stoves (low storey buildings). DH/cogen represents less than 20 percent of heating in the city. About 90 percent of the central urban population uses gas for cooking. Restaurants are a significant source of ambient emissions because many of them burn coal directly. An estimated 570,000 tpa of coal are burned on commercial stoves.

2. According to the Beijing EPB, in 1985 industrial boilers and kilns were responsible for 68,000 tons of particulate emissions, heating boilers 34,000 tons, commercial stoves 7,600 tons, and household stoves 6,000 tons. In winter, however, family stoves account for 34 percent of particulate emissions and 40 percent of ambient concentrations of TSP. Heating boilers are responsible for 35 percent of TSP, and production boilers 24 percent. Environmental controls vary significantly. About 90 percent of the industrial boilers have been improved, with most large boilers apparently having precipitators.

3. Data from WHO air pollution monitoring stations in Beijing indicate annual average concentrations of TSP ranging from 226 to 594 $\mu g/m^3$, with 24-hour maximum readings of over 2,700 $\mu g/m^3$ (1982). The daily average TSP ambient concentrations correspond to Class II and Class III national standards. There has been a trend downwards in the last three years.

4. Estimated total SO_2 emissions for 1985 were 532,000 tons, primarily from industrial and electric power sources. WHO data on SO_2 between 1981 and 1988 indicate annual average concentrations of as low as 7 to as high as 249 $\mu g/m^3$, depending on location. The highest 24-hour maximum recorded by WHO during this period was 886 $\mu g/m^3$. These readings exceed the Class II and Class III national standards.

Shanghai

5. Shanghai is the largest city in China with a population of 14 million. The area is highly industrialized and depends heavily on coal. Annual coal consumption is 24 million tons (although this does not include the supply of all state enterprises in the metropolitan area); coal is transported from

Shanxi and Anhui. About one-third of the coal is used by electric power stations, 10 percent in the domestic sector, and 10-20 percent for coke production. The remainder is used largely in industrial boilers, the textile industry and the chemical industry. There are 9,000 boilers of varying sizes in the Shanghai area (heating boilers are not allowed as Shanghai is not in the central heating zone). Emission control efficiency varies widely. Cyclones, with TSP removal rates up to 90 percent, are used on industrial boilers. Power plants use electrostatic precipitators.

6. Air pollution studies indicate that industrial boilers are responsible for 70 percent of ambient concentrations, large power plants 15 percent and domestic sources 10 percent. Ambient concentrations of TSP in Shanghai lie within or outside Class II standards, depending on location. SO_2 concentrations fall within or just outside Class II standards. The pH level of rain in some parts of Shanghai averages about 5, with readings sometimes down to a value of 4.

7. Projected expansion of the electric power industry in Shanghai is expected to make air pollution more difficult to control in future years. The current capacity is 3,000 MW, but this will be doubled by 1993. New power stations will be fitted with electrostatic precipitators designed to remove 98 percent of TSP emissions.1/ TSP emissions from industrial plants will be strictly controlled. All industrial boilers must be fitted with dust collectors, and removal rates must be at least 90 percent, regardless of stack height. Studies are underway to determine how to control sulfur emissions.

Shenyang

8. Shenyang uses about 5.5 million tons of coal per year. Industrial use accounts for 4 million tpa, households 0.5 million tpa, district heating 0.8 million tpa, and the commercial sector 0.25 million tpa. Shenyang is a city well known in China for its program to reduce coal related pollution, and among other measures it has strongly promoted use of briquettes instead of raw coal. Unfortunately, because of local availability of lignite, the briquettes are composed of one-third lignite, a poor quality coal which should not be used in households. About 150,000 tpa of ROM high volatile bituminous coal is still used in outlying households, but no raw coal is allowed to be used in restaurants and cafes.

9. WHO monitoring data indicate that Shenyang has very high ambient concentrations of TSP, exceeding even the Class III Standard. Progress has been made since 1981 in reducing TSP concentrations, but further reductions must be made. SO_2 emissions in Shenyang also exceed the Class III standard. Maximum 24-hour concentrations up to 1,126 $\mu g/m^3$ have been recorded.

1/ It should be possible to install precipitators with an efficiency of over 99 percent. Even a 1 percent change in effectiveness can be significant in terms of the volume of emissions reduced.

Chongqing

10. Chongqing is one of the worst polluted cities in China, largely from coal pollution. The sulfur content of coal mined and used in the Chongqing area averages 4.5 percent and may be as high as 8 percent. Even when put through coal washery processes to reduce ash content and sulfur, the sulfur content of treated coal can still be about 2.7 percent.

11. Chongqing city (central city) has a population of 1.7 million. The urban area covers 85 km^2, giving a population density of 20,000/km^2. The population of outlying areas is 14.6 million, with an average density of 631/km^2. The larger area contains a mixture of rural, industrial, and urban residential activities. Total primary energy use in Chongqing in 1988 was 13.67 MTCE, with industry accounting for 8.5 million tons. Approximately 70 percent of primary energy use is coal. The urban area of Chongqing contains cement factories, electric power stations, and metallurgical industries. Cement, brick and lime kilns are located mostly in the outer sections but still close to populated areas. In the city, industrial boilers are the main source of emissions, but emissions controls are inadequate. Households use egg-shaped briquettes from coal fines because they are cheap. Some honeycomb briquettes are produced, but they are not the majority. Only a small percentage of households use gas.

12. Industrial activities account for about 67 percent of TSP emissions, restaurants 20 percent and the household and service sector 13 percent. SO_2 emissions average 1,183,000 tpa with 835,000 tons released in Chongqing city and 348,000 in the outer areas. Coal use accounts for 95 percent of SO_2 emissions.

13. The Class III air quality standards are exceeded in Chongqing. Ambient concentrations of TSP range from 560 to 710 $\mu g/m^3$ and average 620 $\mu g/m^3$. Daily average ambient concentrations of SO_2 vary from 300 to 400 $\mu g/m^3$, three times the Class III Standard. The pH levels of acid precipitation range from 4.09 to 4.27, with some readings as low as 4.07. Natural topographic and meteorological factors account for the high ambient concentrations of air pollutants in the Chongqing area. Temperature inversions occur 80 percent of the year, but the effect is worst in the winter when coal use for heating is high. The Chinese authorities say the health effects of this high sulfur coal use are evident: 34 percent of the central population suffers from chronic bronchitis, and the incidence of cancer is rising (it is difficult, however, to isolate the cause of the latter).

14. There are plans to improve environmental conditions in Chongqing. These include the use of methane gas from mines in place of direct coal combustion, increased coal beneficiation, and further installation of emission control equipment on industrial facilities. According to the Chongqing EPB, Y 800 million will be needed to reverse trends in air pollution.

Jiangsu Province

15. Jiangsu Province covers an area of 100,000/km^2. The average population density is 700/km^2 in the nonurban areas and 20,000-30,000/km^2 in the cities. The province is a major user of coal; in 1987, coal consumption was

58 million tons. Power stations use about 13 million tons. Other important industrial users are fertilizer plants, iron and steel plants, brick kilns and textiles factories. Approximately 14 percent (5.34 million tons) was used by households; over 90 percent of households use briquettes. Air pollution activities in Jiangsu province is exacerbated further by emissions from neighboring provinces--from the northeast during winter, and from provinces in the southeast during summer. These include emissions from the Shanghai industrial area and Anhui. Ash disposal is also a problem. For example, at one large power plant, one-third of the fly ash is presently dumped into the river pending construction of a new ash disposal pond (mid-1990).

16. Ambient concentrations of air pollutants are monitored in four major cities of Jiangsu province (Wuxi, Suzhou, Changzhou and Zhenjiang), although monitoring is not continuous. TSP concentrations exceed the Class II standard, and in Zhenjiang, where there is a large power station, they exceed the Class III standard. Annual daily average SO_2 concentrations exceed the Class II standard in all four cities, and exceed the Class III standard in Wuxi and Zhenjiang. The Jiangsu EPB claims that 70-80 percent of the province is affected by acid rain; pH levels fell below 4.5 at 25 percent of the monitoring points in 1987.

Shanxi Province

17. Shanxi has five major coalfields and large unexploited reserves. In the north, the province has large deposits of steam coal; the central and southern parts contain anthracite and all varieties of coking coal. Coal production in Shanxi province in 1988 was 247 million tons, of which 98 million tons were produced by the state mines under MOE, 35 million tons by provincial mines, and 114 million tons by county/township mines. Shanxi has a very high energy intensity relative to output value, and it appears that considerable coal is wasted, including some coking coal from local mines which is used for noncoking purposes.

18. Part of the problem in Shanxi is that there is a lot of small-scale industry associated with individual mining areas throughout the countryside. For example, there are many beehive coke ovens operating in the mining area which supply small foundries. Such primitive coke ovens are inefficient, waste coal, and are polluting. These types of ovens are common in coal-producing regions (they are found also in Chongqing). In contrast, they have been shut down in most areas of East China and the industrial centers of the Northeast. There are also many small-scale ammonia, cement and brick plants in Shanxi.

19. Shanxi suffers from considerable pollution problems including mine waste accumulation and air and water pollution. Many coal-related industries (steel, coking, cement production) are based in Taiyuan, the provincial capital. Coal use in Taiyuan (with a population estimated at 2 million) exceeds 8.28 million tpa. Industrial boilers are the main source of emissions. Ambient concentrations of TSP are more than twice the Class III standard, and SO_x concentrations are just within the Class III standard.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Household Energy Analysis 1/

1. Some simple projections have been run to show potential growth in coal use in the household sector.2/ A base urban population of 300 million in 1987 is assumed. A high and low scenario (5 percent and 3 percent per annum, respectively) are provided for urban household growth by 1995 and 2000. Assumptions were made regarding unit household energy demand for both cooking and heating. Different scenarios for coverage of gas and DH are shown to give some idea of the magnitude of urban coal use and the impact of increased gas use and DH coverage. It should be emphasized that this is a first attempt. More work is needed to improve overall understanding of household energy demand.

2. Assumptions Regarding Cooking. Energy demand for cooking is about 3 million to 4 million kcal/year/household, depending on the fuel and combustion efficiency. Because of its higher efficiency of use, gas consumption is estimated at about 3.0 million kcal/year (it is also used for water heating). The heat equivalent of briquettes allocated for cooking appears to be higher than this. In the North, briquette allocations are equivalent to 6.5 million kcal/year, though of course part of this is used for heating; in Wuxi (southern Jiangsu) the annual briquette allocation is equivalent to about 4.2 million kcal.3/ Because of the greater efficiency of cooking with gas, it would seem reasonable to assume an overall gas consumption of 3.0 million kcal/year/household, rising over the period to 3.4 million, and a level of 4.0 million kcal/year/household for coal/briquette cooking. In the future, it is unlikely that gross fuel needs for cooking will increase significantly. Rather, with higher incomes, the trend will be towards a cooking fuel which can provide convenience and cleanliness. This means either gas or electricity.

3. Gas Coverage. The urban gas coverage projections used here are in line with those of the Urban Construction Administration. They assume, by year 2000, that about 120 million people, or about 30 million households, will be supplied with some form of gas; thus, 20-30 percent of the total urban

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1/ This analysis is based heavily on the report by M. Prior.

2/ There were several problems in trying to do these projections. Only aggregate numbers for urban coal consumption were given, which include commercial and public establishments. No exact breakdown between cooking and heating was available. Moreover, estimates of the urban population and its growth rate are debatable.

3/ All these conversions are made from gross tonnage allocations rather than actual consumption. A fixed calorific value of 5,000 kcal/kg is assumed. Both these assumptions are vulnerable to error.

population will be covered.3/ Various sources are assumed. The coal used in coal gasification is not included in the coal consumed.

4. Heating. The simplest parameter measuring unit consumption of energy for heating is the gross fuel input into the boiler supplying hot water to apartment radiators. The actual heat supplied to households will depend upon the efficiency of the boiler (estimated at about 55 percent for small block-heating boilers) and losses in transferring hot water to an apartment (typically about 15 percent but depending very much upon the size of the heating area and design of piping). Information from various parts of China suggests that unit coal consumption varies from 34 kg coal/year in Beijing to as much as 45 kg coal/year in cities further north.4/ The consumption level is, of course, a factor of the severity and length of the winter season as well as boiler and apartment design. Average apartment area is usually quoted as being 45-50 m^2. Coal consumption in apartment blocks heated by individual building boilers is assumed to be 40 kg/m^2/year or 10 million kcal per year, rising to 11 million kcal by 2000. Coal briquettes for heating stoves are assumed to provide close to equivalent heat (about 10.5 million kcal per year). Heating demand is likely to show a steady rise, with increases in income, reaching effective saturation only at high comfort levels.

5. The targets used by the Chinese authorities for coverage of district heating is that by the year 2000, 25-30 percent of the households in the 70 major cities of the heating zone will be covered. In this analysis, it is assumed that 18-24% will be covered. If district heating is combined with power generation, the unit coal consumption is much less than for central heating, an estimated 11.5 kg coal/m^2/year. It is assumed that block heating systems consume about 37 kg per m^2.

6. Electricity. No calculations are made for electricity demand. There is an implicit assumption that some of the increase in unit household heating demand (as incomes rise) is likely to be met by electricity use (the coal consumption implied by this electricity use is not calculated).

3/ This is much less than the figure of 40 percent so often quoted; the latter estimate is for "major" cities.

4/ It is assumed throughout that coal has a standard heat content of 5,000 kcal/kg.

Table 1

HOUSEHOLD ENERGY ANALYSIS

Household Energy Demand in China

	1990	1995	2000
NUMBER OF HOUSEHOLDS (M)			
Heating zone			
High (5% p.a. growth)	43.7	55.6	70.7
Low (3% p.a. growth)	40.6	46.8	54.1
Transition zone			
High	16.8	21.4	27.2
Low	15.6	18.0	20.8
Non-heating zone			
High	23.5	30.0	38.1
Low	21.8	25.2	29.1
Total Households			
High	84.0	107.0	136.0
Low	78.0	90.0	104.0
Apartment size (m2)	50	50	50
COOKING FUEL			
1. Gas			
Annual cooking demand (M kcal)	3.0	3.0	3.4
Gas coverage (M households)	13.4	20.6	29.4
Total need (M kcal)	40.1	61.9	100.0
of which:			
Natural gas	20.0	32.9	51.5
LPG	9.3	11.7	17.0
Coal-based	7.2	13.7	28.0
Heavy oil-based	3.1	3.1	3.1
Other	0.5	0.5	0.4
3. Raw Coal or Briquettes			
Energy demand/household (M kcal)	4.2	4.2	4.2
Total coal demanded			
High (M tons)	59.3	72.5	89.5
Low	54.3	58.3	62.7

Household Energy Demand in China

	1990	1995	2000
HEATING REQUIREMENTS			
1. District Heating			
Total area (M m2)	145	340	650
DH/Cogen			
% of DH	64%	56%	53%
Coal Input (M tons) a/	1.1	2.2	4.0
DH/Heat Only			
% of DH	36%	44%	47%
Coal Input (M tons) a/	1.9	5.6	11.3
Total Households Covered	2.9	6.8	18.0
% of Total Households			
High	7%	12%	18%
Low	7%	15%	24%
2. Dispersed Boilers			
No. of households			
High scenario	23.3	32.1	43.6
% Coverage	53%	58%	62%
Low scenario	21.4	26.0	30.3
% Coverage	53%	55%	56%
Demand/household (Mkcal) a/	10.0	10.5	11.0
Coal Input			
High	46.6	71.8	95.9
Low	42.9	58.8	66.6
3. Direct Coal or Briquettes for Heating			
No. of Households			
High scenario	17.5	16.7	14.1
% Coverage	0.40	0.30	0.20
Low scenario	16.2	14.0	10.8
% Coverage	0.40	0.30	0.20
Coal Input (M tons)			
High scenario	36.7	36.7	32.5
Low scenario	34.1	30.9	24.9

a/ Coal consumption by type of system: DH/cogen = 11.5 kg/m2;
DH/Heat only = 37 kg/m2; dispersed boiler = 42 kg/m2

	Household Energy Demand in China		
	1990	1995	2000
TOTAL COAL USE IN HOUSEHOLDS (M tons)			
Coal/Briquettes in Cooking			
High	59.3	72.5	89.5
Low	54.3	58.3	62.7
Coal/Briquettes in Heating			
High	36.7	36.7	32.5
Low	34.1	30.9	24.9
Total Raw Coal/Briquette Use			
High	96.0	109.3	122.1
Low	88.4	89.2	87.5
Coal in Heating Boilers			
District Heating	3.0	7.7	15.3
Dispersed Boiler Heating			
High	46.6	71.8	95.9
Low	42.9	58.8	66.6
Total Coal Consumed			
High	145.6	188.8	233.2
Low	134.2	155.7	169.4

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Coal Briquettes 1/

A. Background on Briquetting Processes

1. In Europe, sized coal is used in some households and in industrial boilers to ensure efficient combustion with minimum particulate emissions. In special cases, where the fine coal is particularly valuable (for example, anthracite fines), it can be financially viable to reagglomerate the fines into larger pieces to produce a high-value smokeless fuel for use in domestic appliances or industrial grates. The motivation for briquetting in China is to enable coal fines and high-ash anthracite to be burned with acceptable efficiency and environmental impact, because graded coal is unavailable to most consumers (due to lack of screening and blending).

2. Domestic smokeless fuels can be produced via cold or hot briquetting processes. The first step in selecting an agglomeration process is to assess the feedstock coal properties and the requirements of the briquette product. Briquetting is a rather specialized, technical "art" because of the varied properties of coal and binder materials. Briquetting processes can be separated into those processes which require a binder to effect agglomeration and those processes which can be described as binderless. Further divisions can be made as to whether the process occurs at low temperature (up to 100°C) or at higher temperatures (usually 300-1,000°C).

3. As coal rank increases, agglomeration without a binder only becomes possible at elevated temperature with the use of special briquetting processes. For anthracite, binders are always necessary, and the briquette generally must undergo some form of heat treatment, depending on the required properties of the briquette. There are obviously some intermediate processes in which bituminous coals are briquetted with a binder and anthracite is briquetted apparently without a binder. The latter would appear to be the case in some cities in China. But the anthracite feedstock in China has so much naturally occurring clay that it acts as a binder. The briquette produced in China is, by Western standards, very fragile and degrades easily when handled. From an emissions standpoint, however, it is effective, producing significantly lower emissions than raw coal; in fact, Chinese honeycomb briquettes made of anthracite would likely meet UK smokeless fuel standards (<5 grams/hour of emissions).

4. All briquetting processes incorporate operations in which the feedstock coal is formed via compaction. The different shapes and sizes of the product agglomerate are functions of the compaction equipment used. Feedstock

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1/ This annex benefited from the data and analyses in Working Paper No. 2, Energy Research Institute, SPC. It draws heavily from background reports by A. Gibson and by the Coal Research Establishment (British Coal).

preparation will involve all or some of the following: drying; crushing; and blending of a binder. Some coals may be devolatized via curing prior to or after briquetting.

B. Briquettes for the Household/Service Sector

5. Briquettes of various types are used in China to reduce consumption of raw coal in households. The type of briquette used depends on the appliance in which it is used, each appliance being suitable only for a particular type of briquette. Briquettes for use in small cooking stoves are in general use in many cities, but the extent of use varies. One estimate is that they account for about 50-55 percent of coal used in urban cooking, with the percentage being higher in some northern and eastern cities. The larger cities and more well-off areas promote use of briquettes, but there are indications that, in many smaller cities and towns and in rural areas, briquettes are not commonly used. In Nanjing and Wuxi, no raw coal is used in urban households, although there is direct coal use in surrounding suburban areas. This is a typical pattern. The central cities, organized under long-standing allocation systems, have been able to promote briquette use effectively. Outlying areas around the cities, in various stages of transition to "urban" status, depend more on direct coal use.

6. Most restaurants continue to burn coal directly, despite efforts to promote briquette use in the commercial sector. Briquettes typically do not give the intensity of heat that direct coal burning does, making them unpopular among restaurants. The emissions from restaurants and other commercial establishments represent a significant source of low-level pollution. Teahouse boilers and service sector stoves reportedly account for as much as 20 percent of ambient concentrations in major cities. Emission controls are poor, and they have very low stack heights.

Types of Briquettes

7. Honeycomb Briquettes for Cooking. Briquettes of honeycomb shape are now promoted most widely, although weaker egg-shaped briquettes (with higher ash content) are still used in some areas. The honeycomb briquette is a low cost way to use high ash coal; the ash itself acts as a structure in which the carbon burns. Anthracite (with an ash content up to 40 percent) and anthracite fines are used for the feedstock. In Beijing, for example, local anthracite of 30 percent ash is used. In fact, a honeycomb briquette made of low ash coal (e.g., 10 percent) would not work, because it would then not agglomerate without curing. The briquette shape and strength (even though comparatively weak) are retained during combustion, thereby keeping combustion air paths open and supporting the weight of additional briquettes above it.

8. While the authorities often mention that a sulfur absorbent (lime) is used as a binder, in practice clay and loess also are used. Lime is a weak but acceptable binder, and it fixes sulfur. It is also relatively cheap and appears to be available throughout China. It was not possible to ascertain, though, whether lime is always used in briquettes. This is an important question because it affects the extent of sulfur emissions from briquette combustion. About 95 percent of the sulfur will appear in the flue gas. If lime is used as a sulfur sorbent, then sulfur emissions are reduced. The extent of

sulfur absorption depends on the sulfur content of the coal. The sulfur binder also reduces the calorific value of the fuel, however.

9. The honeycomb briquettes are relatively large (0.5 to 1 kg in weight) and cylindrical, with a series of lengthwise holes to admit combustion air. They are used mainly in the domestic sector but are also used in schools and canteens. They are generally ignited at the bottom and burn upwards since the material used in their manufacture is smokeless. In some cities, a small number of igniter briquettes are also made for bottom-lit briquettes, since firewood is scarce. Cooking stoves are often kept lit, and not allowed to go out, to avoid relighting.

10. "Top-Lit" Bituminous Briquettes. In order to create more choice in feedstock (perhaps because of lack of locally available supplies of anthracite), a "clean burning" bituminous briquette has been developed for use in cooking stoves; called a top-lit honeycomb briquette, it is being used in Shenyang.2/ The smokeless nature of these briquettes depends on them being lit at the top and burning downward, countercurrent to the upward flow of air. The means by which this occurs is really a function of the appliance design. The principle of operation is that combustion occurs downward, countercurrent to primary air flow; secondary air is added over the top of the combustion zone so that the volatile matter is burned off in the hot zone.

11. In practice, however, most top-lit briquettes are not burned "top-lit", but rather in the conventional bottom-lit way. There are two reasons: (i) the top-lit briquette requires an igniter briquette which is expensive (Y 69 per ton) and fragile (made of wax, maize, straw, lignite and chemical waste); and (ii) the top-lit system is slow to heat up (taking 40 minutes compared to 20 minutes for a conventional bottom-lit system). The latter is an important disadvantage in areas of the country where the fire is used intermittently and is relit at least once per day, such as in Shenyang and other northern cities where "bed heating" is practiced. Hence, householders prefer to light the briquettes at the bottom which enables cooking to start sooner.

12. There has been some success in restaurant use. Top-lit briquettes are used in those restaurants where they can be kept lit and the ignition problem does not arise. But raw coal is still preferred. In small water boilers (hot water for tea making, some bathing and use of steam for heating lunchboxes), top-lit briquettes are also used properly because the briquettes can be kept permanently lit. Thus, in Shenyang, while all briquettes are designed to be top-lit, roughly 80 percent of all briquettes are used in the

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2/ This approach was born out of necessity in Shenyang, as the feedstock used includes both bituminous coal (35 percent) and lignite (40 percent), in addition to some anthracite (25 percent). A lignite mine on the outskirts of Shenyang was developed to provide a feedstock for a modified fixed bed gasifier of Eastern European manufacture. The gasifier failed to operate successfully for technical reasons and is now out of service. The mine is still producing, however, and the city decided to use the coal in the domestic sector.

conventional manner (bottom-lit). The published data on environmental benefits of using these briquettes refer to top-lit combustion, however, which is misleading.

13. An alternative approach may be to develop improved downburning stoves, which could burn bituminous briquettes with low emissions. Such stoves have been developed in the UK (6-10 kW capacities); they reduce smoke emissions from high volatile coals by 90 percent or more, and most comply with the UK Clean Air Act.

14. Tea Boiler Briquettes. A special form of the honeycomb briquette is used in hot water boilers. They are cylindrical in shape with a diameter of 100-120 mm and a height of 75 mm; each briquette has 13 longitudinal holes. Larger briquettes of 220 mm diameter are used in some cafeterias and restaurants. A newly developed integrated briquette is used in some water boilers; the boilers provide hot water for tea making and central heating for some buildings. The integrated briquette is cubic with a 100 mm side with holes across two faces.

Production and Distribution

15. Production methods for honeycomb briquettes are practically identical in all cities and are based on the principle of centralized feedstock preparation with briquette production in dispersed, small plants. This decentralized production method is necessary since the briquettes are extremely weak and easily degraded. Anthracite fines are the main feedstock, although other locally available coals are sometimes used. The briquettes are made by preparing a feedstock which, along with some water, is fed through a horizontal table press. The press has a double acting stamp and a die of the appropriate shape (cylindrical or cubic), the combustion holes being pushed out by the second action of the stamp. The material pushed out during formation of the holes is recycled to the feedstock. The honeycomb briquette press usually has one stamp, though two-stamp machines are used in some cities. An improvement in pressing might be to use presses with more stamps or to adapt pressing techniques used in the brickmaking industry. Unfortunately, because the briquettes have to be removed from the machine's discharging conveyor by hand, it is doubtful whether a press with more than two stamps would be practical.

16. For both production and distribution, a large number of workers are employed. At plants visited, five presses with a total production of 16,000 tpa employed 100 people (in the UK, a briquette plant of 150,000 tpa would require 60-70 people). Because the briquettes are weak and have no water resistance, they have to be handled very carefully and stored under cover. Both these factors add to the cost of production and distribution. The necessity for covered storage and limitations on stock heights reduces available storage capacity; thus, production capacity must meet peak demand in winter.

17. Distribution is labor-intensive because of the fragility of the briquettes. The feedstock is transported in trucks over fairly large distances to dispersed production centers. The briquettes themselves are transported by flat-decked tricycles in small quantities (sufficient for one or more families' monthly allocation) over short distances and are loaded and unloaded by

hand. Mechanical handling and transport by lorry would result in almost total degradation of the product. Again, because of the high ash, the briquettes have poor calorific value. Thus, transport and production costs on an energy basis are high. They also contribute to the very serious ash disposal problem in urban areas. Still, the briquettes are an improvement over use of ROM coal.

18. Monthly allocations per family usually range from 100 to 140 briquettes per month depending on the city and area of the country. In Shenyang, the allocation is 150 kg per month, plus an additional 400 kg during the heating season. The total annual allocation is therefore 2.2 tons per family, though it is claimed the average usage is only 1.5 tons.

Pricing

19. Honeycomb briquettes are sold consistently at a lower price than raw coal. According to Chinese authorities, this requires a government subsidy of Y 25-75 per ton, depending on location and how the subsidy is measured. Briquettes in Wuxi, for example, cost 2.2 fen each (0.5 kg); additional amounts above the allocation cost 11 fen each. Using existing prices/costs to estimate a "financial" average incremental cost (AIC), the subsidy appears to be about Y 60-70 per ton (refer to Table 1). There is tremendous pressure, therefore, to reduce costs, and it appears that municipal governments try to rely on locally produced coals for briquette production. In Shenyang, for example, briquettes are made partly from lignite coals because the government has access to these locally produced coals.3/ In other parts of Liaoning province, poor quality gas coal is being directly burned in households.

20. At Attachment 2 are estimates of average incremental costs for two types of honeycomb briquettes, based on both financial and economic prices.4/ Table 1 provides a summary of the results and compares them with existing briquette prices. It demonstrates the heavy subsidization of briquettes in line with raw coal and other fuel subsidized at the household level.

Types and Efficiencies of Stoves

21. Cooking Stoves. Domestic briquette stoves are simple devices and well suited to the use of honeycomb briquettes. They are simple open-topped, cast iron cylinders containing a ceramic liner.5/ The liner is of a size which just accepts a cylindrical honeycomb briquette. The rate of combustion is controlled by opening or closing a small slide at the base of the stove to admit more or less combustion air. The stove is portable, has no flue, and

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3/ Lignite, a poor quality coal, is a bad choice for household use because it is smokey.

4/ The economic cost is derived by using market prices for coal and adjusting investment costs by shadow economic factors.

5/ A typical stove costs Y 15 and will last in excess of 20 years. The linings cost about Y 2 for a type which lasts about five years. These stoves will also burn ball briquettes, but those briquettes are being phased out as they are inferior to the honeycomb.

therefore has to be used outdoors or in a well ventilated room. It is kept lit at all times as far as possible. The housewife generally cooks three times per day for one hour on each occasion. The air damper is opened up just before cooking and closed afterwards. A metal plate is then placed on the stove. The usage therefore covers about 3-6 hours of cooking; for the remaining 18-21 hours, the stove is slumbering. This results in a drastic reduction in efficiency.

Table 1: ACTUAL VS. AVERAGE INCREMENTAL COSTS OF BRIQUETTES

City	Coal used	Briquette prices (yuan/ton)	Estimated AIC Financial	Estimated AIC Economic /a
Beijing	Anthracite	28	99.4	150
Shenyang	Various coals /b	32	92.6	140/c
Wuxi/Nanjing	Anthracite	44	NA	NA/d

/a Economic prices are assumed to be: Y 120-150 for bituminous coal and anthracite fines; Y 80 for lignite.
/b The "top-lit" briquette made in Shenyang uses a combination of 40 percent lignite, 35 percent bituminous and 25 percent anthracite.
/c The lower cost is deceptive, as there should be a penalty for using lignite, a poor quality coal, in households.
/d Production costs are probably similar to those in Beijing except that coal supply costs would be higher because of higher transport costs.

22. Heating Stoves. North of the Yangtze River, where heating is permitted, a larger stove, normally with a flue pipe, is used in the heating season for both cooking and heating. The construction is cast iron with a ceramic liner appropriate to the briquette size being used. In some areas, bed heating is practiced. The family bed is made on a brick base, and flue gases from the stove are passed through the base before leaving the building. The hot flue gases heat up the bricks which act as a storage heater. However, the stove has to be allowed to go out every evening to ensure that the householder does not suffer from CO poisoning. The fire is then relit every morning.

23. In regard to the CO question, it is difficult to gauge to what extent the briquette stoves used in the heating season are vented. Not infrequently, it appears that stoves are used unvented, which poses a serious health problem, especially during the night when air circulation is reduced. Potential CO emissions and related problems require more investigation and should be quantified more systematically.

24. Stove Efficiencies. One would expect a doubling of efficiency when going from raw coal to briquettes because less coal is used to achieve the same total calorific value. Still, the small honeycomb briquette stove is likely to have an efficiency of less than 25 percent because it is used for cooking, and the flue gases are not used. As mentioned above, the stove is used only 3-6 hours per day for cooking, but continues to consume fuel for

18-21 hours of 24. Improving the turndown capabilities of the stove should be a priority in order to improve efficiency. When a stove having a flue is used for cooking and bed heating, the efficiency will be better because the heat in the flue gas is used to heat the bed; despite this efficiency, this practice should be discouraged for safety reasons and, wherever possible, a central heating system should be installed. Tea boilers using integrated briquettes may achieve a much higher efficiency--perhaps 50-60 percent.

Other Solid Fuel Options

25. Stronger Briquettes. Use of Western briquetting techniques (low or high temperature curing) could produce a strong, waterproof smokeless fuel, which would offer easier transport and handling; would involve less ash disposal (because they are made from washed anthracite); and could be used in larger, more efficient appliances. A potential technique, relatively low cost, is a "mild heat treatment" process (MHT) used in the UK. This process is cited because it represents the cheapest method of converting anthracite fines to briquettes which are relatively strong and waterproof and can be used in more efficient closed appliances. The MHT process involves curing at generally less than 300°C.6/

26. Other, stronger briquettes (involving curing at higher temperatures) should also be investigated. These briquettes will be more expensive, but savings in handling and in energy efficiency must be factored in. High temperature cured briquettes might also offer lower emissions. More effort is needed to consider and develop such intermediate technologies for more efficient coal use in households. They may be more affordable than programs like DH and coal gasification in the medium term.

27. Washed Anthracite. An alternative, perhaps even more promising from the standpoint of emissions, would be to produce washed lump anthracite. Sized, washed anthracite is an excellent smokeless fuel and could be used in Chinese briquette stoves, provided a different liner is used. The smaller sizes of anthracite would require modification of the stove. Clean lump anthracite could also be used exactly as Western briquettes in more efficient appliances. In the UK, for example, anthracite "grains" (+6.3 mm) and anthracite "beans" (+11 mm) are used in free standing gravity fed boilers or in room heaters. A larger grade is used in cooker/boilers and room heaters.

6/ The anthracite is dried, crushed and blended with a binder, which could be molasses, lignosulphonate or modified penetration grade bitumen. The briquettes are then cured in the presence of oxygen at temperatures of 280-380° for about one hour on a "conveyor oven" system. The briquettes are then cooled by a combination of air cooling and water quenching. Typical properties of these briquettes are: size = 35-60 grams; volatile matter = 5-11 percent; ash content = 6-9 percent; crushing strength = >100 kg. An industrial briquette plant (first of its kind) now being built in Chongqing will use what is essentially an MHT process (see discussion below at para. 34); hence, the technology is already available in China. Indeed, this process may have greater potential for household briquette use than in industry.

28. Applications in More Efficient Appliances. Both cured briquettes and washed, lump anthracite could be used in a cooker/boiler with heat transfer to water and then use of the hot water for heating and bathing; maximum turndown of the appliance would also be possible. The overnight banking or slumbering would provide hot water for bathing. The efficiency of such appliances are compared below with the Chinese briquette cooking stove:

- cooker + domestic hot water (UK) 40-50 percent
- cooker + domestic hot water + central heating (UK) 68 percent
- honeycomb briquette stove (China) <25 percent

The cost of a cooker/boiler appliance would be more expensive. A cooker/boiler of the type mentioned above in the UK could cost about 1,500 pounds sterling. However, it would seem possible to develop similar appliances which could be manufactured in China. While such alternatives would be more expensive than honeycomb briquette stoves, considering energy efficiency they may be justified. They are options to be considered and researched, as more emphasis is given to environmental mitigation and improved heat supply, particularly for use in housing, where options such as the supply of gas are unavailable.

Emissions

29. At Attachment 1 is a comparison of potential emissions from raw coal, washed coal and briquettes. This analysis was done as a desk study, using ranges for typical coal types and ranks in China. Without the benefit of actual testing, a number of parameters had to be estimated; therefore, the results must be considered indicative only. Still, they provide a picture of the relative magnitude and range of emissions from different coal types. Adjusted for calorific value, the results can be summarized as follows:

Table 2: INDICATIVE EMISSIONS FROM DIFFERENT SOLID FUELS

Solid fuel type	kg/1,000 MJ	
	TSP	SO_2
Raw bituminous coal	0.7	0.21-2.7
Raw anthracite	0.032	0.13-1.16
Washed anthracite	0.028	0.08-0.83
Anthracite briquettes /a	0.035	0.07-1.01
Bituminous briquettes (top-lit) /a	0.14	0.14-1.96

/a With lime binder.

The most striking result is the difference in TSP emissions for raw bituminous coal compared with those of washed anthracite or briquettes on a calorific basis. Raw bituminous coal generates 25 times more emissions than washed anthracite and 20 times more than anthracite briquettes. The ranges for SO_2 emissions are 170 percent higher or more. The comparison with lignite would be even worse because of its lower calorific value.

30. Another important result of the analysis is the differences indicated between use of anthracite briquettes and recently promoted top-lit bituminous briquettes. While better than raw coal, top-lit bituminous briquettes emit four times as much TSP as anthracite briquettes and two times as much SO_2. The conclusion, therefore, is that anthracite briquettes (with lime) should be promoted over top-lit briquettes. The differences in emissions are great enough that authorities should concentrate, as an immediate step, on maximizing the supply of anthracite in briquettes going to household users.

31. The comparison between washed anthracite and anthracite briquettes also has important ramifications. Washed anthracite is likely to emit 20 percent less TSP than the briquettes on a calorific basis. In regard to SO_2, the comparison is more ambiguous. When the sulfur level of the anthracite feedstock is low, the briquettes (with lime) emit less SO_2 than washed anthracite. The higher "apparent" sulfur capture is due to dilution of the fuel weight with lime. With low sulfur content, 40 percent of potential SO_2 is retained, while with a high sulfur content, 20 percent is retained. At higher levels of sulfur, washed anthracite appears to have the advantage.

32. Washed anthracite on a per ton basis will be more expensive than anthracite briquettes in terms of capital and operating costs of production. But overall costs and benefits should be considered: emission reductions, lower transport and ash disposal costs and greater energy efficiency when using washed anthracite in more sophisticated appliances.

Suggested Elements of a Household Fuel Strategy

33. Many households depend on burning raw coal or briquettes in small cooking and heating stoves. Since desired investments in gas supplies for cooking and district heating cannot be expanded quickly to cover the majority of households, a medium-term strategy is required to improve solid fuel use in households. The following steps are recommended:

- As an immediate step, authorities should promote and even make mandatory the use of low ash anthracite or anthracite briquettes instead of raw coal in household stoves throughout the country in urban and rural areas. Use of bituminous coal or lignite should be phased out as far as possible.

- Anthracite honeycomb briquettes should be promoted over top-lit bituminous briquettes.

- Environmental and municipal authorities should also investigate the benefits and costs of using sized, washed anthracite or high-temperature cured briquettes in more efficient household appliances. Cost-benefit analyses, considering economic costs of distribution and ash disposal and the calorific value of the coal products, should be undertaken.

- There are considerable supplies of anthracite in China, but high quality supplies are not going to the household sector. Policies and incentives are needed to assure a sufficient supply of good quality anthracite to households. Rationalization in the ammonia and cement industries could help reduce pressure on high quality anthracite (refer to discussions in Annex 9). A study of the anthracite market is needed to analyze all the ramifications.

C. Development of Briquettes for Industrial Boilers

34. Ball briquettes are widely used in production of ammonia-based fertilizers. This is discussed in Annex 9 (ammonia industry). In addition, various research groups in China are experimenting with production of briquettes for use in industrial boilers. The objective is to reduce the fine coal used in boilers and to capture some of the sulfur with a binder. Since Chinese coals are generally high in fines, low combustion efficiency results, due to high undergrate loss, and higher particulate emissions occur from fines escaping in the flue gas. At present, commercial production of industrial briquettes is very limited. In 1989, a plant was being built near Chongqing (Sichuan province), and there were reports of plants being built in Jiangsu and Guangxi.

35. The Chongqing plant intends to produce 200,000 tpa of 20 gram briquettes. Raw bituminous coal will be screened, and the resulting fines (<13 mm material) used as feedstock. Crushed lime will be added to the feedstock to fix the sulfur content; a binder of lignosulphonate will be used. After pressing, the briquettes will be dried and cured (at 180°C with a residence time of 75 minutes); during curing, briquette strength will be increased from 5 kg to 50 kg; at such strength it will not be completely waterproof. Generally, the process is typical of modern European briquetting plants. But the curing conditions and briquette properties are different.7/ The fundamental difference in briquette quality is the binder.8/ The mechanics of roll pressing are also the same, but the materials used reflect a philosophy of using inexpensive materials replaced often, rather than using longer lasting high quality steel.

36. The use of briquettes in industrial applications is uncommon in OECD countries because industrial users would buy sized coal (screened and graded). In the UK, briquettes are not used in industrial grate boilers because they are much more expensive than graded coal, which is freely available. Briquettes made in the UK are used mainly in household appliances. While the industrial briquettes proposed for use in China would increase combustion efficiency and reduce particulates, heat release rates are likely to be

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7/ Lignosulphonate-bound briquettes in West Germany and the UK typically involve curing conditions of 280-320°C for about 90 minutes. The briquettes have crushing strengths of 150 kg and are substantially waterproof.

8/ Lignosulphonate is a by-product of the paper making industry. In Europe, paper is made from wood pulp. In China, however, paper is generally made from grass and wheat/rice straw. The linings derived from these materials have very different properties from those derived from wood pulp.

reduced (in the absence of perhaps expensive boiler modifications).9/ Briquettes would increase efficiency because fines are not lost. However, because of their larger surface area, they would burn slowly compared to raw coal or pellets, the latter an alternative option (see below). An industrial boiler operator needs to extract the energy from his fuel quickly as well as efficiently. Thus, briquettes could result in boiler derating (i.e., its steam output will be reduced).

37. Pelletization of Fines. There may be a better way to achieve the same objective of higher combustion efficiency and lower particulate and SO_2 emissions, while retaining high surface area and, hence, heat output. It is to produce a briquette of much smaller size than that produced in a double roll press. One inexpensive method would be to use a pellet mill, which is a device which produces coal pellets with a diameter between 9 mm and 12 mm, depending on the die used in the mill. The preparation of the coal feedstock would be identical to that used in honeycomb briquette plants, subject to achieving a suitable moisture content. But the equipment used to produce the final agglomerate would be different. Binders which have been found suitable are starch, molasses and lime and bentonite clay. In China, where high ash bituminous coals are used, it is probable that, if lime is used to fix sulfur, no binder would be required.

38. Binderless bituminous coal pelletizing would be recommended for small-scale production immediately upstream of the moving grate of the boiler. A recommended approach would be to centralize feedstock preparation but to disperse the pelletization operation--similar to the approach used in making honeycomb briquettes for household use. Small pellet mills closely linked to boilers or furnaces would be a reasonable option. The feedstock could be fed through the pellet mill into a small surge hopper which feeds the traveling grate of the boiler. In this case, the pellets would only need sufficient strength to cope with feeding and discharge from the hopper. The cost of a very small pellet mill (1-5 tph) in China would be similar to the cost of a honeycomb briquette machine.10/

39. For larger scale, centralized pelletization, a binder and post-pelletizer curing would be required. Centralized pelletization would create more durable products, but degradation might still be a problem. The processing would be the same as that for briquettes except that the final compaction would involve a different machine. The production cost would probably be close to the estimated cost for industrial briquettes.

9/ Chinese authorities state that heat release rates will not be reduced since the boiler combustion chamber will be modified, and the briquette is formed in a special patented way, which causes it to break in a controlled direction, hence exposing more surface area for combustion (called a "bursting into bloom" technique).

10/ The smallest pellet mill in the UK is 3 tons per hour (tph); it serves a boiler of 23 tph steam output, assuming 80 percent efficiency and a fuel of 5,000 kcal/kg. It costs less than 3 percent of the total boiler cost.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Pollutant Emission Ranges for Solid Fuel Options /a

Emission Range (kg/metric ton)

Fuel Type	TSP	SO_2	CO	NO_x	BaP	CO_2
Anthracite	1	4-36	110	2.1	$<1.5X10^{-3}$	$2.4X10^3$
Bituminous	20	6-76	105	2.0	$1.5X10^{-3}$	$2.3X10^3$
Lignite	20-25	10-114	75	1.4	$>1.5X10^{-3}$	$1.6X10^3$
Honeycomb Briquettes (Anthracite)						
With lime (7%)	1	2-29	100	1.9	$<1.5X10^{-3}$	$2.2X10^3$
Without lime	1	4-36	110	2.1	$<1.5X10^{-3}$	$2.4X10^3$
Honeycomb Briquettes (Bituminous)						
With lime (8%)	4	4-56	100	1.8	$1.5X10^{-3}$	$2.1X10^3$
Without lime	4	7-76	105	2.0	$1.5X10^{-3}$	$2.3X10^3$
Washed Anthracite /b	1	3-30	130	2.5	$<1.5x10^{-3}$	$2.8x10^3$
MHT Briquette	1-2	7-47	105	2.0	$1.5X10^{-3}$	$2.3X10^3$

/a Based on typical data on ranking of Chinese coals and ranges for ash and sulfur. In some areas, this data was supplemented by basic data relating to coal composition and coal combustion. As this was a desk study, emission ranges can only be considered to be tentative estimates. See below for assumptions used in estimating emissions. Estimated calorific values are as follows:

Solid fuel type	MJ/kg (as received)
Anthracite (unwashed)	31
Bituminous	28.5
Lignite	20
Anthracite (washed)	36
Briquetted Anthracite	31
Briquetted Anthracite + 7% lime	28.6
Top-lit Bitum. Briq. + 8% lime	28.5
MHT	28.6

/b For washed anthracite, it has been assumed that a high quality washed anthracite could be produced and that this would represent a 15% decrease in the combined moisture and ash content, with a concomitant increase in calorific value.

Assumptions:

1. It is assumed that sulfur contents are supplied on an "as received" basis and that 95% of the sulfur is released as SO_2. For the addition of lime to capture sulfur dioxide (7-8% by weight), it has been assumed that for the lowest S contents 40% of the emitted SO_2 is retained, while for the highest S contents 20% of the emitted SO_2 is retained. The higher "apparent" S capture is due to dilution of the fuel weight with lime.

2. CO values are based on typical UK experience that CO emissions are likely to be around 1% by volume in the flue gas at 6% O_2. Variations are due to changes in moisture and ash content.

3. NOx values are based on typical UK experience using a value for a domestic appliance of 75 ppm NO_2 at 6% O_2. Variations are due to changes in moisture and ash content.

4. Benz-a-Pyrene are impossible to estimate with accuracy. The values given are based on a typical value for the domestic combustion of bituminous coal and the < or > indications are related to the extent of volatile matter in the fuel itself.

5. Regarding CO_2 emissions, the following carbon contents (as received) have been assumed:

Anthracite	78.0%
Bituminous	72.5%
Lignite	51.3%

CO_2 emissions have been calculated assuming an 84.5% release of carbon as CO_2. The remaining carbon is accounted for by losses in smoke undergrate or in ash and as CO emissions.

Table 1

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Honeycomb Briquettes Analysis (anthracite, bottom lit)- Beijing

(End 1989 prices)

	Economic			Financial		
	Quantity (ton)	Unit price (Y/ton)	Total (M Yuan)	Quantity (ton)	Unit price (Y/ton)	Total (M Yuan)
A. Costs:						
a. Total capital investment			28.00			20.00
b. Raw materials costs (p.a.):						
Anthracite	263,736	120.0	31.65	263,736	56.0	14.77
Lime	26,374	120.0	3.16	26,374	120.0	3.16
Slime/ loess	39,560	40.0	1.58	39,560	40.0	1.58
Subtotal	329,670		36.39	329,670		19.51
c. Other costs (p.a.):						
Labour			0.05			0.81
Power			0.97			0.75
Management & tech.			3.30			3.30
Maintenance			0.80			0.80
Transport			0.90			0.90
Tax			-			1.20
Subtotal			6.02			7.76
Total operation cost (b & c):			42.41			27.27
B. Total products (p.a.):	300,000			300,000		

Table 2

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Honeycomb Briquettes Analysis (anthracite, bottom lit)- Beijing

(M Yuan; End 1989 prices)

Years		Economic Costs Capital	Economic Costs Operation	Economic Costs Total	Economic Total production (M ton)	Economic Average cost (Y/ton)	Financial Costs Capital	Financial Costs Operation	Financial Costs Total	Financial Total production (M ton)	Financial Average cost (Y/ton)
1		14.00		14.00			10.00		10.00		
2		14.00		14.00			10.00		10.00		
3			42.41	42.41	0.30			27.27	27.27	0.30	
4			42.41	42.41	0.30			27.27	27.27	0.30	
5			42.41	42.41	0.30			27.27	27.27	0.30	
6			42.41	42.41	0.30			27.27	27.27	0.30	
7			42.41	42.41	0.30			27.27	27.27	0.30	
8			42.41	42.41	0.30			27.27	27.27	0.30	
9			42.41	42.41	0.30			27.27	27.27	0.30	
10			42.41	42.41	0.30			27.27	27.27	0.30	
11			42.41	42.41	0.30			27.27	27.27	0.30	
12			42.41	42.41	0.30			27.27	27.27	0.30	
13			42.41	42.41	0.30			27.27	27.27	0.30	
14			42.41	42.41	0.30			27.27	27.27	0.30	
15			42.41	42.41	0.30			27.27	27.27	0.30	
16			42.41	42.41	0.30			27.27	27.27	0.30	
17			42.41	42.41	0.30			27.27	27.27	0.30	
18			42.41	42.41	0.30			27.27	27.27	0.30	
19			42.41	42.41	0.30			27.27	27.27	0.30	
20			42.41	42.41	0.30			27.27	27.27	0.30	
Total		28.00	763.38	791.38	5.40		20.00	490.86	510.86	5.40	
NPV	10%	24.30	287.46	311.75	2.03	153.32	17.36	184.84	202.19	2.03	99.44
	12%	23.66	245.10	268.76	1.73	155.01	16.90	157.60	174.50	1.73	100.65
	15%	22.76	196.51	219.27	1.39	157.74	16.26	126.36	142.62	1.39	102.60

Table 3
CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Economic Analysis of Honeycomb Briquettes (top lit)

(End 1989 prices)

	Beijing				Shenyang			
	Quantity (ton)	Finan. price (Y/ton)	Econ. price (Y/ton)	Total (M Yuan)	Quantity (ton)	Finan. price (Y/ton)	Econ. price (Y/ton)	Total (M Yuan)
A. Costs:								
a. Total capital investment				28.00				22.40
b. Raw materials costs (p.a.):								
Lignite	-		-	-	140,000	37.50	90.0	12.60
Bituminous	164,835	105.00	150.0	24.73	120,000	72.00	100.0	12.00
Anthracite	98,901	56.00	120.0	11.87	80,000	102.00	150.0	12.00
Lime	26,374	120.00	120.0	3.16	12,000	120.00	120.0	1.44
Slime/ loess	39,560	40.00	40.0	1.58	48,000	12.00	12.0	0.58
Subtotal	329,670			41.34	400,000		96.6	38.62
c. Other costs (p.a.):								
Labour				0.05				0.11
Power				0.97				1.03
Management & tech.				3.30				3.50
Maintenance				0.80				0.64
Transport				0.90				0.45
Subtotal				6.02				5.73
Total operation cost (b & c):				47.36				44.35
B. Total products (p.a.):	300,000				350,000			

Table 4

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Economic Analysis of Honeycomb Briquettes- Shenyang

(M Yuan; End 1989 prices)

Years	Costs: Capital	Costs: Operation	Costs: Total	Total production (M ton)	Average cost (Yuan/to
1	11.20		11.20		
2	11.20		11.20		
3		44.35	44.35	0.35	
4		44.35	44.35	0.35	
5		44.35	44.35	0.35	
6		44.35	44.35	0.35	
7		44.35	44.35	0.35	
8		44.35	44.35	0.35	
9		44.35	44.35	0.35	
10		44.35	44.35	0.35	
11		44.35	44.35	0.35	
12		44.35	44.35	0.35	
13		44.35	44.35	0.35	
14		44.35	44.35	0.35	
15		44.35	44.35	0.35	
16		44.35	44.35	0.35	
17		44.35	44.35	0.35	
18		44.35	44.35	0.35	
19		44.35	44.35	0.35	
20		44.35	44.35	0.35	
Total	22.40	798.30	820.70	6.30	
NPV 10%	19.44	300.61	320.04	2.37	134.91
12%	18.93	256.32	275.24	2.02	136.07
15%	18.21	205.50	223.71	1.62	137.94

<u>Table 5</u>

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Economic Analysis of Honeycomb Briquettes- Beijing

(M Yuan; End 1989 prices)

Years	Costs Capital	Costs Operation	Costs Total	Total production (M ton)	Average cost (Yuan/to
1	14.00		14.00		
2	14.00		14.00		
3		47.36	47.36	0.30	
4		47.36	47.36	0.30	
5		47.36	47.36	0.30	
6		47.36	47.36	0.30	
7		47.36	47.36	0.30	
8		47.36	47.36	0.30	
9		47.36	47.36	0.30	
10		47.36	47.36	0.30	
11		47.36	47.36	0.30	
12		47.36	47.36	0.30	
13		47.36	47.36	0.30	
14		47.36	47.36	0.30	
15		47.36	47.36	0.30	
16		47.36	47.36	0.30	
17		47.36	47.36	0.30	
18		47.36	47.36	0.30	
19		47.36	47.36	0.30	
20		47.36	47.36	0.30	
Total	28.00	852.48	880.48	5.40	
NPV 10%	24.30	321.01	345.30	2.03	169.82
12%	23.66	273.71	297.37	1.73	171.51
15%	22.76	219.45	242.21	1.39	174.24

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

District Heating (DH) 1/

A. Introduction to District Heating

Types of District Heating

1. District heating is a form of central heating whereby heat is supplied from a producing plant to a consuming area via a transmission and/or distribution network.2/ There are several forms of district heating: (i) DH by cogeneration of heat at a power plant, also called CHP (combined heat and power); (ii) DH using waste heat from an industrial plant; and (iii) block heating (DH using heat-only boilers fueled by coal, oil or gas).

2. The capital costs of DH are substantial, particularly in the case of DH/CHP. Therefore, prior to making such investments, a careful economic evaluation of all heating options should be undertaken. The following criteria are important in considering the economics of DH:

(a) availability of a low cost, base load energy source close to the consuming area;

(b) high heat demand density;

(c) high load factor and low fluctuations in heat load demand;

(d) favorable construction conditions for pipe networks;

(e) suitable building installations (modern radiator and metering systems);

(f) strong environmental requirements; and

(g) ability to invest large sums in public utility systems.

The criteria for high heat demand density and relatively small peak heat loads reflect the need to utilize the full capacity of a DH system for long periods.

1/ This annex is based on reports and analyses by A. Christensen and Y. Albouy.

2/ Central heating includes all types of heating systems where the heat is transferred from a heat source (boiler, heat exchanger, etc.) to a radiator system, and the media transporting the heat is either water or steam (hot water is more common and considered more economical. Central heating therefore covers both district heating and heating of individual buildings by small boilers.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

District Heating (DH) 1/

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2. The capital costs of DH are substantial, particularly in the case of DH/CHP. Therefore, prior to making such investments, a careful economic evaluation of all heating options should be undertaken. The following criteria are important in considering the economics of DH:

(a) availability of a low cost, base load energy source close to the consuming area;

(b) high heat demand density;

(c) high load factor and low fluctuations in heat load demand;

(d) favorable construction conditions for pipe networks;

(e) suitable building installations (modern radiator and metering systems);

(f) strong environmental requirements; and

(g) ability to invest large sums in public utility systems.

The criteria for high heat demand density and relatively small peak heat loads reflect the need to utilize the full capacity of a DH system for long periods.

1/ This annex is based on reports and analyses by A. Christensen and Y. Albouy.

2/ Central heating includes all types of heating systems where the heat is transferred from a heat source (boiler, heat exchanger, etc.) to a radiator system, and the media transporting the heat is either water or steam (hot water is more common and considered more economical. Central heating therefore covers both district heating and heating of individual buildings by small boilers.

has remained virtually static, as use of low-cost abundant fossil fuels and electricity has overshadowed many of the advantages of district heating. The existing DH systems are mainly steam systems using oil as primary fuel, and today they cover less than 1 percent of total energy for space heating and hot water.

6. In Europe, the most extensive DH systems are in the USSR and Eastern Europe. Among Western European countries, hot water-based district heating systems have developed with success in parts of the more northern countries during the post-war period. The Federal Republic of Germany has the largest system (including DH/CHP), although market penetration is higher in the Scandinavian countries (20-40 percent of total residential space and water heating requirements). Investments in DH systems in Western Europe have been highly dependent on the energy situation in individual countries.4/

7. Several features are common to those cities in Western Europe which have invested in DH systems. First, they have sustained heat demand during long winters and no appreciable air-conditioning loads during summer. Second, DH/CHP is normally used as base load, while small oil or gas fired units, located in consuming areas, meet peak demand. This pattern has evolved over time. During the 1950-60 period, a great number of smaller--often oil-based --district heating systems were constructed to supply apartment blocks. Individual houses and other residential apartments were usually heated by light oil-fired central heating systems. The large extension of DH systems actually took place after the oil crisis in the 1970s. DH offered the possibility of converting to a cheap alternative fuel (coal) while at the same time controlling the environmental impact caused by coal burning.5/ DH systems were extended by interconnecting the existing DH networks by transmission pipes. The smaller oil-based DH boilers became peak load boilers, and base load was met by cogenerated heat.6/

8. A third factor affecting the economic success of district heating systems is the density of the area served (demand of at least 5 MW per km of

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4/ Various countries or regions decided against district heating because of economic and institutional factors. Even in areas with high winter heat demand, DH has not always been economic. Converting to a new heat source implied substantial depreciation costs with regard to the replaced network as well as heating systems in buildings. Power plants were sometimes too far from consumers to be connected to a DH system, and large utility plants also worried about the effects of DH on plant reliability.

5/ Another factor which encouraged DH development at the time was that DH systems could easily be converted to any cheap primary fuel available. When planning the big extensions of DH systems in Europe, there was great uncertainty about future energy prices. DH offered the possibility to utilize low grade fuels such as heavy fuel oil, coal, solid waste, etc., but it could be converted to natural gas or light oil, if the price of such fuels later favored a conversion.

6/ Other sources of base load heat, besides utilities, have been industrial plants with waste heat and solid waste incineration plants.

pipeline is required) and the rate of utilization of the system. For instance, in Denmark, the hook-up of consumers larger than 1 MW is mandatory in DH supply areas in order to assure high utilization. If smaller consumers subscribe, they normally must agree to purchase heat for a minimum of 20 years.

9. DH/CHP was originally considered cost-effective due to the high energy prices in the 1970s. Today, district heating systems are still built in Europe, but not because of the low heat cost. Taking present fuel costs into account, cogeneration is not economic compared with heat-only boilers, because of the big investments required in cogeneration and transmission systems.7/ The primary motive now is the environmental benefits offered by such systems when burning coal. DH/CHP reduces coal consumption and coal-related emissions. Of course, in Europe, DH is an alternative competing with light oil-fired individual boilers, natural gas and electricity, not small-scale, coal-based heating as in China. On the other hand, most Western European countries were financially better off than China before making the substantial investments in district heating.

B. District Heating in China

Background on Heating in China

10. Heating Zones. There are large climatic differences among regions in China; therefore, the extent of heating varies considerably. Heating facilities are officially allowed in only the northern part of the country. China is divided into three zones: (a) the heating zone, where central heating and other modes of heating are permitted between November 15 and March 15 (although there is some variation in start-up dates); (b) the transition zone, where there are no central heating facilities, but coal allocations for individual household stoves are increased during the most severe winter months; and (c) the nonheating zone where no heating is permitted, roughly, south of the Yangtze River). A map showing the different zones is at Attachment 2. The central urban population in these zones is estimated below:

Zone	Urban residents 8/ (center cities only)
Central heating zone	110 million
Transition zone	40 million
Nonheating zone	60 million

11. Forms of Heating. Urban households have three official sources of heat:

7/ Most Danish district heating systems can offer heat at a competitive price compared with the alternative fuel (light oil). But this is because oil products are subject to heavy taxation in Denmark.

8/ The central heating zone includes Northeast, Northwest and North China. North China includes: Beijing, Hebei, Henan (northern part), Inner Mongolia, Shaanxi, Shandong and Shanxi.

(a) coal stoves (those normally used for cooking or somewhat larger stoves primarily used for heating);8/

(b) central heating from coal-fired boilers heating individual or several buildings; and

(c) district heating systems (by CHP or block heating).

In the central heating zone, 50-65 percent of heating is by dispersed single building boilers; 30-45 percent is by stoves burning coal or briquettes; and less than 10 percent is by DH.9/ The major change occurring in urban fuel use over the past ten years has been a switch away from coal stoves for heating toward central heating by small boilers. This reflects a shift in building type in the cities. People often use their cooking stoves for heating in the transition zone and other areas where heating is not officially permitted.10/

12. Heating Standards. It is important to note that present heating levels in China are uncomfortable and low by world standards.11/ In the heating zone, the intended indoor room air temperature is 18°C (64°F), but in practice this is not usually achieved. In Beijing, for example, actual temperatures are generally 13-16°C but can be lower. Before start of the heating season, temperatures in houses can go down to 9°C. In the transition zone, in cities such as Shanghai or Wuxi, room air temperatures on cold winter days can be 2-6°C. The poor standard of heating is exacerbated by the lack of insulation of buildings and bad window design, which contribute to heat losses.

District Heating Systems in China

13. Concern over ambient level pollution from coal stoves and small heating boilers and pressures for a higher standard of living have led to selective investments in district heating in the official heating zone.12/ DH systems are found in 70 cities in China, but most are not extensive. They supply heat to both residential and institutional buildings; an estimate of the distribution is 60 percent residential, 40 percent institutional. In

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8/ Flue pipes are normally required for heating stoves, although this may not always occur in practice. Use of heat from coal stoves for bed heating occurs in colder regions of the country, although this practice can be dangerous if there is insufficient ventilation.

9/ For example, in Beijing, about 50 percent of heating is by coal stoves, reflecting the significance of older housing in the city.

10/ In Wuxi (Jiangsu province), for instance, allocations of briquettes are increased by 10 percent in winter; people also buy coal on the free market.

11/ The same is true of some other fuel-using activities; for example, apartments usually do not have any hot water supply for bathing.

12/ A system is considered district heating in China if the rated boiler capacity is ≥10 stph and the supply area is ≥100,000 m^2 of floor area.

1988, about 130 million m^2 of floor area were heated by DH, of which about 80 million m^2 represented residential floor area.

14. While there are conflicting estimates, DH/CHP probably represents 60-70 percent of current district heating in China, compared with 30-40 percent for DH from large heat-only coal-fired boilers (block heating). Use of industrial waste energy for heating purposes is very limited; there is probably much greater scope for investments of this kind. Over the next ten years, the announced objective is to increase DH coverage to 25-30 percent of the cities in the heating region. The increase in DH is expected to be met 50 percent by DH/CHP and 50 percent by block heating.

15. The technical features of district heating in China are described in detail at Attachment 3. The typical design tends to give insufficient attention to overall energy economy, affecting various features--the capacity of heating units, the layout of transmission lines, pipe insulation, and building installations.

16. <u>DH/CHP</u>. A typical cogeneration system in China has only one heat producing unit for base and peak heat load. The capacity of that unit and the transmission pipeline therefore correspond to the maximum heat load requirement of the system; no spare capacity is installed. This raises capital costs and lowers flexibility. Co-operation of several heat production units (for base and peak load respectively) would entail the additional investment in modern control and monitoring equipment, however.

17. Usually, the power plant is operated by the electricity company, which supplies the heat to a district heating company. The DH company is in charge of the transmission of the hot water to a number of substations. The hot water is supplied to the buildings through a distribution network connected to the substations. Generally, the owners of the buildings are in charge of operation of the distribution network and the internal systems in the buildings. Institutionally, cogeneration has been difficult in many countries, and China is no exception. In China, the heat is sold at a loss to the power company, in addition to the derating of the utility boiler, creating strong disincentives for the electric power enterprises (under the Ministry of Energy) to cooperate with heating companies (under the municipal authorities) in making the necessary DH investments.

18. <u>Block Heating (DH/Heat-Only Boilers)</u>. Block heating does not require a transmission network or substations; large coal-fired chain grate boilers, operated by the district heating company alone, replace the cogen unit and substations used in CHP. The distribution network, heat load control and building installations are the same as those for CHP. The advantages of block heating over dispersed boilers in individual buildings are the better efficiencies offered by larger boilers and the more effective pollution control equipment that can be installed. On the other hand, compared to DH/CHP, it uses more coal, and block boilers may have less efficient pollution control than power plants.

19. <u>Building Installations</u>. Centrally-heated buildings in China traditionally have single string radiator systems with no means of control of the

individual radiator and consequently no means of control over indoor temperatures in individual apartments. When rooms become overheated, residents simply open windows to regulate the temperature, consequently wasting heat. Applying manual or automatic controls (control valves) to single string radiator systems is very difficult; it is a problem obtaining hydraulic balance and correct cooling of the district heating water. Consequently, single string radiator systems are regarded as unsuitable in modern DH systems in Western Europe.

20. Heat Charge Structure. The present heat charge system does not encourage efficient use of heat. The bulk of the cost of heating is paid by the institution or company employing the residents in a particular building. The occupants pay only a small fee. Moreover, heat charges are based on the floor area of individual apartments, not on actual heat supplied. There are usually no meters at the point of supply to a building and no valves in individual apartments to measure consumption. Thus, owners and occupants have no incentive to make investments which save energy or to adopt energy-saving habits. The higher operating costs ultimately become a burden on the municipal government, however, as it ultimately must supply more energy for heating.

Economic Analysis of Heating Options

21. To understand more clearly the trade-offs among central heating options, a comparative analysis based on estimated economic costs was undertaken. Three different options for residential heating were considered: (i) central heating of individual buildings by small, dispersed boilers; (ii) DH by large "block" heating boilers; and (iii) DH/CHP from power plants. The only other major source of heat supply not considered in the analysis are the small coal or briquette burning stoves.13/

22. The comparison was based on a fictive supply area, comprising 6 million m^2 of residential floor area. A design heat load of 60 kcal/hr per m^2 floor area and a design heat demand of 720 billion kcal/season (0.12 million kcal/season per m^2 of floor area) were assumed. Investment requirements and operating costs were estimated for each option, applying unit costs; financial costs were adjusted by shadow price factors.

23. In the case of DH/CHP, estimates were made for a cogen unit with heat extraction capable of supplying the required heat to the target area. Only the incremental investments related to cogeneration and transmission were actually charged. However, since heat production causes a derating of the electrical output, that derating was included in the operating costs of the DH/CHP option. Until the year 2000, the derating was valued at a shortage cost of Y 0.5/kWh, which takes into account the opportunity cost of industrial production foregone because of power shortages. Afterwards, the derating was valued at the cost of the power supply.

13/ Use of industrial waste heat for district heating, while potentially very economic, was not considered here as a major supply source, although it will be important wherever there are opportunities to make such investments. See also the discussion in Chapter V of the main report.

24. For individual building and block heating systems, the number and cost of boilers needed to supply heat to the target area were estimated. Coal consumption (adjusted by boiler efficiencies) was estimated as follows: for dispersed boilers--44 kg/m^2; and heat-only boilers--37 kg/m^2. Distribution costs were charged in both block heating and DH/CHP. The cost of building installations were charged in all three options. Attachment 4 lists the full assumptions used, including estimated financial costs and economic conversion factors.

25. The average incremental costs of the heat supplied, based on economic costs, were calculated under several scenarios: three different coal prices (Y 100, Y 150 and Y 200/ton); a slower connection rate; and a 20 percent higher construction cost. The analyses are shown in Attachment 5 and the results summarized in Table 1.

Table 1: COMPARISON OF COSTS OF HEATING OPTIONS
(Yuan/Gcal) /a

Cases	Dispersed boilers	DH/ Heat only	DH/ CHP
1) Coal at Y 100 per ton /b			
Financial	95	85	89
Economic	118	117	179
2) Coal at Y 150 per ton			
Economic	136	133	181
3) Coal at Y 200 per ton /b			
Economic	155	149	183
4) Slow connection rate			
Economic	131	132	195
5) 20% increase in investment			
Economic	126	129	192

/a In the table, Gcals are used; the spreadsheet analysis at Attachment 5 uses Gigajoules (1 GJ = 0.239 kcal).

/b Based on 5 million kcal/ton, a typical calorific value for raw coal in China. In the spreadsheet analyses at Attachment 5, tons of standard coal equivalent (7 million kcal/ton) are used (raising the prices on a tce basis to Y 140, Y 210 and Y 280/tce respectively).

26. The results indicate that the average incremental cost of DH/CHP is very high relative to both the other options. This is due to the higher investments costs and the large penalty for derating of electric power. In the base case (a coal price of 100 yuan/ton), DH/CHP is over 50 percent higher than block heating and heating by dispersed boilers. As coal prices go up to

Y 200/ton, the difference between DH/CHP and other options narrows because of the effect of higher coal consumption in the cases of dispersed boilers and block heating. The economic cost of DH/CHP, at Y 200/ton, is then 18-23 percent higher than the costs of the other options.

27. According to the results of this analysis, the least cost option is to invest in block heating. It is more economic than small individual building boilers because larger, more efficient boilers are used, thus saving energy. Block heating is more economic than DH/CHP because there is no electric power derating and transmission investments are avoided.

28. The importance of a quick buildup of the market (quick connection of consumers) is also shown in the sensitivity analysis. A slow connection rate increases the heat price by 9-12 percent.14/ This result confirms the validity of investment guidelines used in Western Europe that there be a ready and sufficient market to connect, once DH investments are completed. The three options considered above are also sensitive to increases in construction costs, although to a lesser extent than to a slow connection rate; the cost increases by 7 percent.

Environmental Impact of Different Options

29. The environmental impact of these different options was also evaluated, again using the assumptions above for the hypothetical supply area. Additional assumptions included the quality of feed coal and the efficacy of pollution control equipment on the three options. The analysis assumes that the feed coal is unwashed with a high ash content--25 percent and a sulfur content of 1.2 percent. An important unknown is the extent to which small dispersed boilers have effective pollution control equipment; a low average rate of removal is applied in this case (30 percent). It is assumed that the most efficient dust removal equipment in China is installed on new power plants (electrostatic precipitators with 98 percent efficiency); the efficacy of control equipment on block boilers is assumed to be 85 percent. These assumptions have an important impact on the results, which are shown in Table 2.

30. While the results shown in the table are sensitive to the assumptions concerning pollution control equipment and content of the coal, the relative positions are clear. Emissions from DH/CHP are substantially less than those of the other two options. In this case, particulate emissions from DH/CHP are 96 percent less than those of dispersed boiler heating and 90 percent less than those of DH/heat only. Sulfur emissions are 70-73 percent less. The main reasons for the favorable emission levels from DH/CHP are:

14/ In most countries, the most severe impact would be found in the cogeneration option, due to the big initial investments in the cogeneration unit and distribution network. But, in China, the impact of a slower connection rate is cushioned by the power benefits--or the lower power derating cost--in the buildup phase (if this phase occurs before the year 2000). Still, there is an increase in the AIC of 9 percent.

(a) the drastic decrease in coal consumption for that option;15/

(b) the more effective pollution control equipment assumed.

Table 2: TOTAL EMISSIONS FOR MODEL CITY
(heating of 6 million m^2 floor area)

	Dispersed boilers	DH/Heat only	DH/ CHP
Coal Consumption (tons)	261,818	223,602	69,000/a
Ash content of coal (%)	25	25	25
Sulfur content (%)	1.2	1.2	1.2
Annual Emission Levels (million kg per season)			
TSP	16	2.9	0.3
Removal rate of pollution control equipment /b (%)	30	85	98
SO_2	6.0	5.1	1.6
CO	0.3	0.2	0.03
HC	0.13	0.11	0.09
NO_x	2.0	1.7	0.5
Emissions Related to Supplied Heat (kg per supplied Gcal)			
TSP	22.2	4.0	0.4
SO_2	8.3	7.1	2.2
CO	0.4	0.3	0.03
HC	0.2	0.2	0.01
NO_x	2.7	2.3	0.6

/a Reflecting the coal consumption for the additional electric power generated to compensate for the derating caused by CHP.
/b Assumptions on extent and efficacy of pollution control equipment are indicative only.

31. A dilemma exists between the much higher economic cost of DH/CHP, particularly over the next ten years in China because of badly needed electric power development, and the substantially greater emission reductions from that option. Coal savings--and reductions in air pollution--will also be achieved by rapid development of more efficient large-scale electric power plants,

15/ The coal consumption assigned to DH/CHP was that associated with the additional power capacity built to compensate for the derating of electric power caused by district heating. Unit consumption was thereby estimated at 11.5 kg/m^2.

without the added investment and derating of district heating (particularly DH systems which are not designed to optimize energy efficiency).

32. The question becomes whether or not there are other more affordable and cost effective solutions to reducing emissions from coal-based heating. Opportunities for fuel switching (to gas for heating, for example) should, of course, be explored, particularly where gas distribution networks already exist. It is very expensive for a city to afford investments in two parallel transmission/distribution networks--one for gas (for cooking) and one for DH. Moreover, a gas network is normally optimized by supplying gas for both heating and cooking. If large-scale coal gasification were necessary to supply sufficient gas, this too would be an expensive solution, just as DH/CHP is. The relative costs would have to be evaluated on a case by case basis.

33. A more affordable strategy may be simply to screen and wash the coal going to small heating boilers and block heating systems.16/ Washing reduces ash and sulfur emissions, although not as dramatically as DH/CHP in a given area. It is less capital intensive, however, and has more applications; therefore, it can be employed more extensively in an urban area. For example, washed coal can be used not only in heating boilers, but also in small stoves and industrial boilers which are also important contributors to ambient concentrations of coal-related emissions. It is important to keep in mind that absolute reductions in emissions in a given area are less important than reducing overall ambient concentrations throughout a city of those emissions most harmful to human health.

Targets for the Year 2000

34. The announced target of the Office of Urban Construction (Ministry of Construction) is that, by the year 2000, district heating coverage is to reach 25-30 percent of residential floor area of cities in the central heating region, with coverage of provincial capitals and cities with special status reaching 50 percent. No estimate of the costs of such a target are available.17/ Moreover, it is not clear how projected growth in urban households is incorporated into these targets. While the targets are set by the central government, it appears that municipal governments are responsible for raising the funds to proceed with DH investments. Many are having difficulty raising funds for such large expenditures.

35. An estimate was made of the investments needed to reach 25 percent coverage of the urban residential area in the heating zone. Tables 4 and 5 show how the estimates were built up. The total residential floor area heated by district heating in 1988 was taken as 80 million m^2, corresponding to 60 percent of the total floor area covered by DH (the remaining floor areas being institutional buildings). The increase in residential floor area over the next ten years was built up using a rate for urban household growth of

16/ Screening, a very low cost investment, will reduce unburned carbon which creates black smoke as it escapes from flue stacks.

17/ The Office of Urban Construction has indicated, however, that the above targets for DH development are subject to change, according to the availability of funds.

3 percent per annum and assuming that 50 percent of the households were in the official heating area. The average construction cost for a complete DH system (including building installations) was estimated at Y 55 per m^2 of floor area, based on the assumption that 50 percent of new district heating systems would be constructed with block boilers and 50 percent with CHP.18/ It did not include any technical enhancements to modernize the present systems used. Nor was expansion of DH to additional public buildings considered.

Table 3: BUILDUP OF RESIDENTIAL FLOOR AREA

	1987	1991	1995	2000
No. of households (million)	73	80	90	104
Total residential floor area /a (million m^2)	3,290	4,000	4,500	5,200
Total heated residential floor area (million m^2)	1,640	2,000	2,250	2,600
Residential floor area covered by DH (million m^2) /b	80	150	340	650
Percentage of total heated area	5	9	15	25

/a Estimated based on best available information. Does not include public buildings.
/b Total area covered by DH in 1987 is 130 million m^2, which includes public buildings.

Table 4: DISTRICT HEATING TARGETS

	1989-91	1992-95	1996-2000	Total increase
Increase in DH over period /a (million m^2)	70	190	310	570
Estimated cost /b (Y billion)	4.4	14.8	29.4	48.6

/a Base floor area assumed to be 80 m^2.
/b 1989 prices have been escalated for inflation as follows: 1990 = 1.14; 1991 = 1.10; 1992 = 1.08; 1993-95 = 1.05; 1996-2000 = 1.04.

18/ The average cost was based on unit costs of Y 50/m^2 for block heating and Y 61/m^2 for CHP. The estimate for CHP did not include required investments in electrical generation, but did include the DH investments associated with cogen units. In contrast, the unit cost of small dispersed boilers is estimated at Y 37.8/m^2.

36. The investments to meet DH targets were estimated at Y 48.6 billion including price contingencies ($10.3 billion)--a pace of about Y 2-4 billion per annum to 1995 and Y 5-6 billion per annum in the period 1996-2000. The capital cost of district heating by block heating only would be about 10 percent lower. Installation of small individual building boilers, the alternative to DH, would be about 30 percent lower. In view of the sizable differences in capital costs, municipal governments may not be able to afford district heating, given that there will be other competing needs for funds in municipal areas. A likely scenario for the next ten years is that certain special or more well off cities will go ahead with some DH investments, but most cities will not reach their DH targets.

C. Recommended Strategy for DH Development

37. Even if the DH targets cited above are met, there will still be heavy reliance on dispersed boilers and small stoves for heating. It is important to remember that the investment requirements cited above will only cover 25 percent of heating for urban residents in part of the country. A cost-effective environmental strategy must therefore provide ways to reduce emissions from the small boilers and stoves which will represent at least 75 percent of heat sources and the bulk of energy requirements for cooking in the year 2000. This suggests that policymakers ought to consider a more practical strategy for heating supplies over that period. The following strategy is proposed:

- Concentrate on lower cost investments to raise the efficiency of heating boilers, to improve the coal supply in urban areas (such as screening and washing of coal) and to introduce improved insulation and modern metering/control systems in new buildings.

- Consider investments in cogeneration using industrial waste heat as a priority.

- Consider other DH investments (DH/CHP or block heating) only in the context of municipal-level cost-benefit analyses designed to identify least-cost solutions to reducing citywide ambient concentrations of pollutants. These analyses should be based on economic costs.19/

- Apply strict design criteria to both DH systems and the housing to be supplied. DH systems should be designed to increase capacity factors, for example by catering to year-round hot water needs. Designs for DH/CHP should include co-operation of heat producing units for base and peak load. Modern control systems should be introduced. (Section D below suggests various modern improvements). New buildings to be supplied should be insulated and modern radiator and meter systems installed.

- Where there is already gas being used and a gas distribution network already exists, in individual cities consider the potential for utilization of additional gas for space heating as an alternative to

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19/ See discussions in Chapters III and VII of the main report.

district heating in order to avoid the major expenses of building two separate distribution networks for gas and DH.20/

- In new areas to be supplied through DH or gas systems, phase in a charge system which includes recovery of economic costs.

D. Recommended Improvements in Chinese DH Systems

Co-Operation of Several Production Units in DH/CHP

38. According to experience in Western Europe, the construction cost of large district heating systems can be limited by using different heat producing units to meet base and peak load. Typical base load units are cogeneration plants; peak load is then covered by cheaper heat-only boilers, fired by gas or light oil (suitable for rapid heat load follow-up). This approach reduces the high construction costs of cogeneration units and also assures that such units are operated at maximum capacity for long periods as base load. Moreover, the peak load boilers are usually located in the supply area (not at the site of the cogenerating power plant), thus reducing transmission pipe sections and thus investment costs.

39. The typical distribution between base load and peak load units is 60 percent and 40 percent respectively. In a typical Danish system, this heat dispatch enables the base load units to supply 90 percent of annual heat demand. The corresponding capacity distribution for a Chinese DH system might differ somewhat, due to the following factors: Chinese DH systems are not operated in summertime; they only supply limited domestic hot water production; and peak loads are lower than in western systems. Still, there should be savings from co-operation.

40. However, co-operation of several heat producing units is more complicated than operation of a single heat production unit. Therefore, it is impossible to implement such a system without installing modern control and monitoring systems. Introduction of automatic controls also requires modification of equipment at the power plant, such as application of speed control for main pumps and modifications of the heat load control concept. The modifications require investments by both the DH company and the power plant.

Heat Load Control

41. In modern systems, the basic control concept is flow control, rather than temperature control (used in Chinese systems). Introduction of control valves at substations and consumer installations (mentioned below) will change the basic control concept from a temperature controlled system to a flow controlled system. Western DH systems rely on control of the pump speed--and, hence, the water flow and pump head--to maintain a fixed differential pressure in the DH network. The water flow in the pipe network will change according to the heat load in the system. The supply temperature is maintained at a constant level. (In a number of systems, however, the supply temperature is

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20/ Moreover, as pointed out earlier, DH distribution networks are 3-5 times more costly than gas distribution networks.

decreased in summertime.) Heat load control, based on water flow, is a very fast reacting system.

Appropriate Temperature Level

42. Cheap base load heat should be produced at a design temperature level not less than 70°C; otherwise, pipe dimensions and pump head requirements, etc. will be very large. Industrial waste heat available at less than this temperature level will normally not be a candidate for DH.

Investments in Consumer Installations

43. For future development of district heating, radiator installations in new buildings should be designed as two string radiator systems, and each radiator should be equipped with a control valve. There are two advantages. First, the individual control of heat would encourage energy conservation and would allow introduction of a charge system based on heat consumption. Second, generally two string systems are easier to adjust to obtain a sufficient cooling of the district heating water, important for efficient operation of the system.21/

44. In regard to existing single string systems, introduction of control valves at each radiator is not possible, as such a solution would require costly retrofitting of single string systems to double string. Instead, it is suggested that equipment be installed to control the supply temperature to individual buildings and to balance the flow in individual radiator strings. Such equipment would typically include a mixing pump for control of the supply temperature, according to the outdoor temperature, by mixing return water into the supply flow to the radiators. To obtain an appropriate flow distribution between individual radiator strings, each string should be equipped with a flow limiting valve.

High Density and Rapid Connection

45. Two other features are important to the economics of DH, particularly DH/CHP: high building and heat load density and rapid connection of consumers. This favors greenfield areas where only high rise residential apartments are being constructed. Existing residential areas, where low level buildings and apartment blocks are interspersed, are problematic.22/ Because of the large initial investments in heat producing units and pipe network systems, it

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21/ High cooling implies that the required heat is supplied using as little water as possible. High cooling decreases pumping costs and heat loss from the return pipe. It also limits the required size of pumps and pipes.

22/ The minimum density for district heating via block heating (to remain competitive with individual building boilers) is approximately 0.4 million m^2 floor area per km^2 surface area, based on the analysis in this study. The corresponding minimum heat load density is about 24 million kcal/hr per km^2 surface area. These are rough estimates; detailed investigations are needed in considering individual projects.

is important that DH systems be utilized at full design capacity in a relatively short time. This means that housing construction in the supply area should be completed before the district heating system comes onstream, and rapid connection of all consumers should occur thereafter. Oversizing of transmission pipe networks and production units to cover planned extension of city areas will usually not be economic, but should be considered in each individual case.

Hot Water Supply

46. Eventually, consideration should be given to supplying domestic hot water year round via DH systems. This would favor the installation of some back pressure turbine capacity owned by nonutility investors, which could then also contribute to the alleviation of power shortages. As the network would be operated in the summer also, it would also imply stopping the present practice of emptying DH systems of water in the summer and refilling just before the heating season. This practice should be stopped in any case, because it encourages faster corrosion. New (treated) water, filled into the pipe networks just before the heating season, contains oxygen and thus accelerates corrosion.

Principles of Combined Heat and Power Production

Three main principles are applicable for design of thermal power plants:

- condensing power plant
- back pressure power plant
- extraction power plant.

The condensing power plant only produce electric power whereas both the back pressure and the extraction power plant also produce heat. These power plants are called CHP-plants - Combined Heat and Power Plants.

The main features of the main principles are briefly stated below:

The Condensing Power Plant

The basic principles in a condensing power plant are illustrated in Fig. 1.

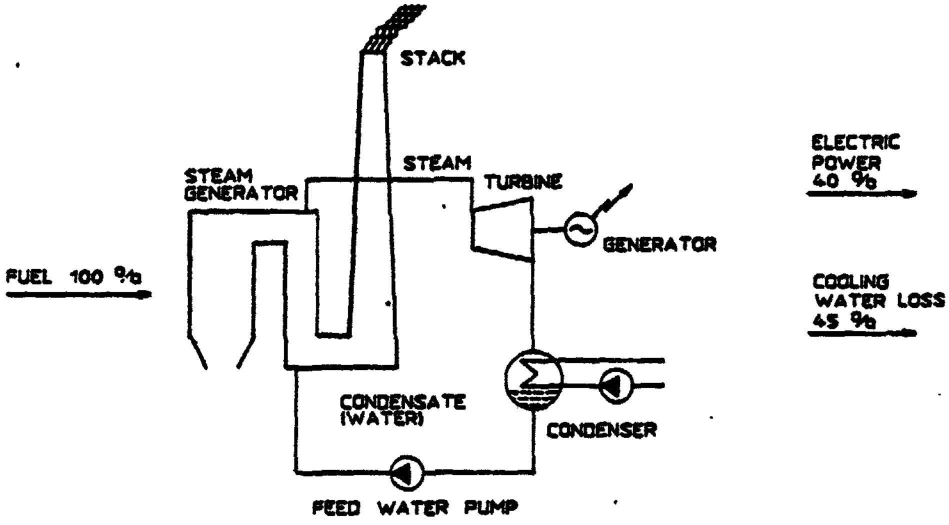


Fig. 1. Condensing Power Plant

Water is pumped into the steam generator. The Fuel - normally coal or oil is combusted and the water is vaporized and steam is superheated. The superheated steam (normally in the range of 540°C, 180 bars) is lead to the turbine. In the turbine the energy of the steam is converted into mechanical energy. The mechanical energy from the turbine is utilized in the generator resulting in an electric power production.

To obtain a large energy conversion in the turbine, the steam pressure at the outlet from the turbine is maintained as low as possible. The low steam pressure is obtained through utilizing low temperature cooling water in the condenser. (Sea water, river water, etc.).

In a condensing power plant typically approx. 40% of the energy content in the primary fuel will be converted into electrical power. The most significant loss is the cooling water loss being approx. 45% of the energy content in the primary fuel.

Back Pressure Power Plant

The basic principles in a back pressure power plant are illustrated in Fig. 2

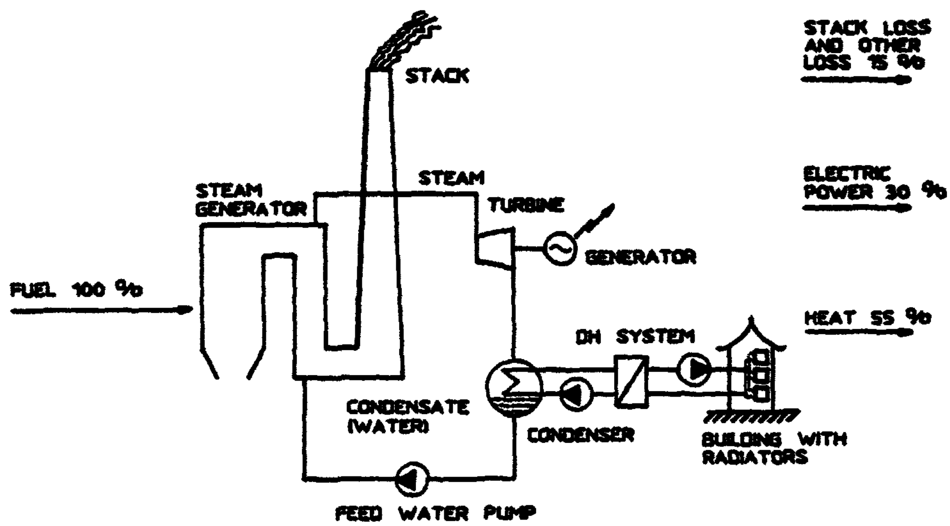


Fig. 2 Back Pressure Power Plant

In the back pressure power plant the large energy quantities in the cooling water are utilised for district heating. A district heating system will require supply temperatures in the range of 100-130°C, and the return temperature will be 50-70°C. The increase in temperature level in the condenser has a very great impact on the outlet pressure at the turbine.

The increased outlet pressure degrades the electric power generation ability of the plant, but the "cooling water" (district heating water) is at a temperature level, which can be utilised for heating of dwellings, etc.

In a typical back pressure power plant 30% of the energy content in the primary fuel is converted into electric power and 55% is utilized for DH water heating. 85% of the energy content in the primary fuel is utilized and only 15% is lost.

All the steam used for heating of the DH water must pass the turbine (and hence generates electric power). Back pressure power plants have a fixed ratio between electric power generation and heat production.

The Extraction Power Plant

The basic principles in an extraction power plant are illustrated in Fig. 3.

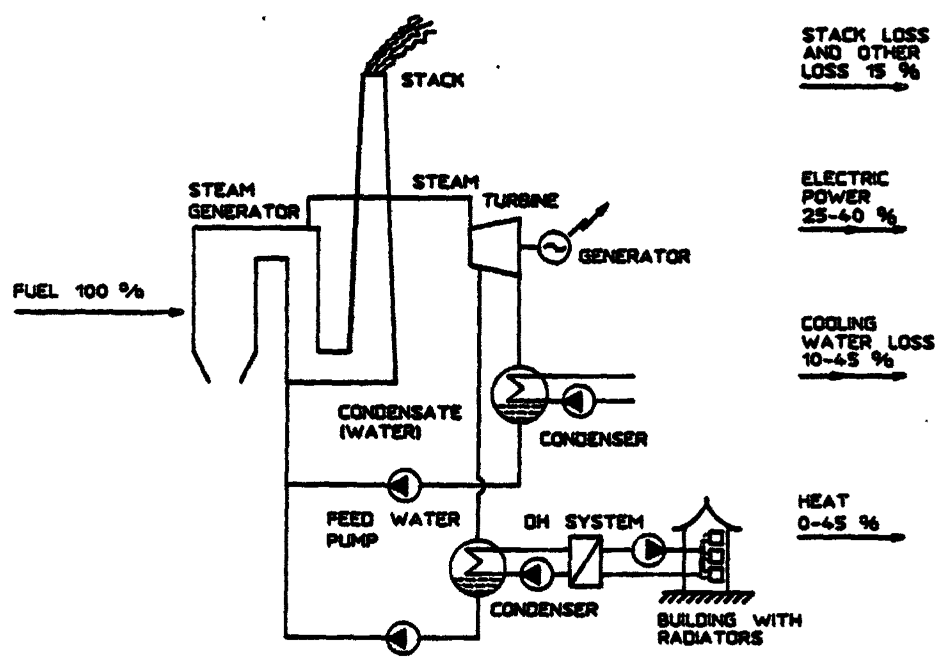


Fig. 3 Extraction Power Plant

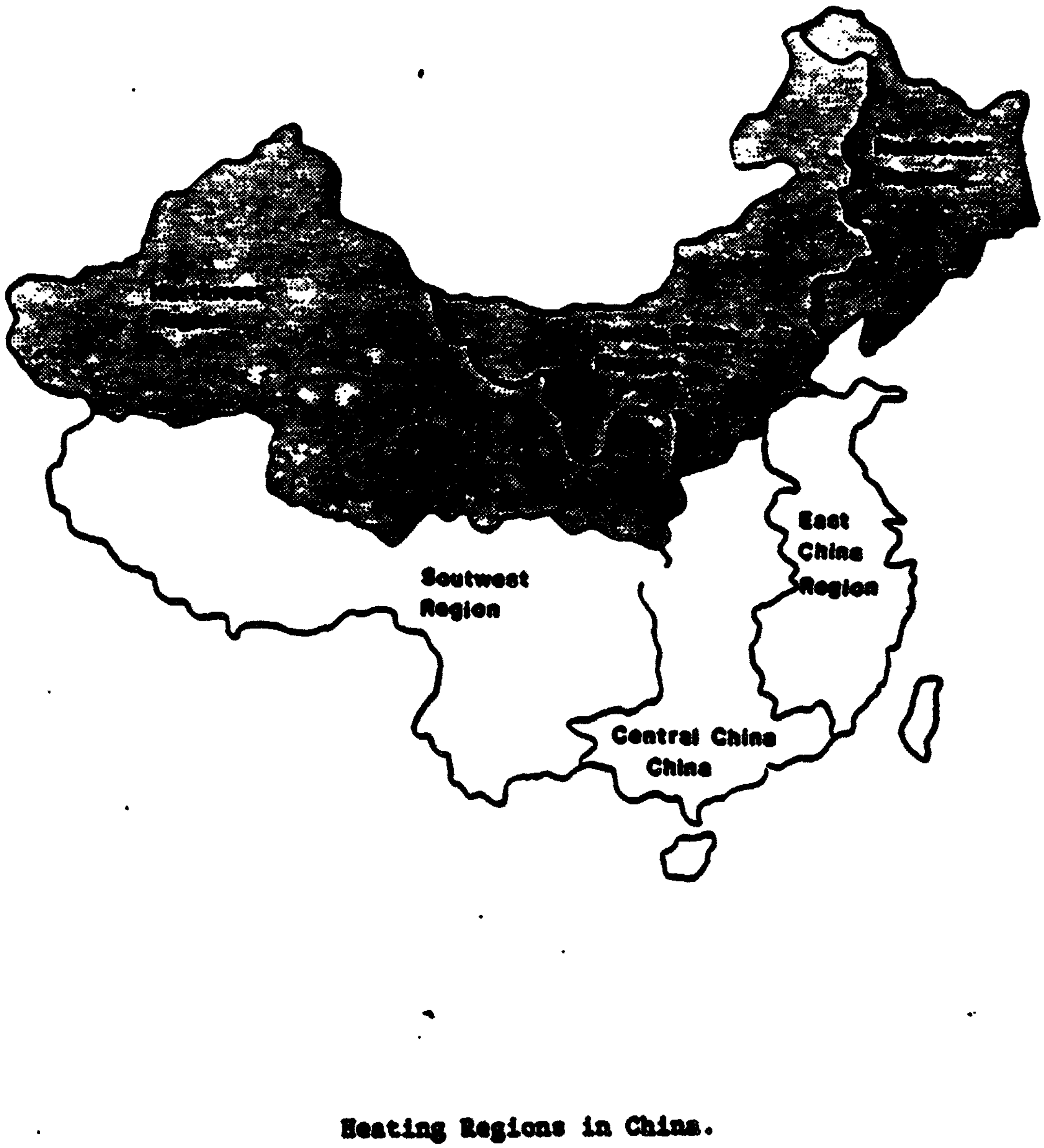
In the extraction power plant, part of the steam flow is extracted from the turbine for heating of the DH-water. The remaining part of the steam flow through the turbine is condensed by cooling water (sea water, river water, etc.).

The steam extraction is adjusted according to the DH heat demand.

An increase in steam extraction cause a decrease in electric power generation, but also a decrease of the energy loss through the cooling water.

For large extraction turbines, the total energy utilization can be varied in the range from 40% (no extraction) to 70% (maximum extraction and minimum possible electric power generation). Depending on the system design, district heating operation temperatures, etc. extraction turbines may be operated in back pressure mode increasing the energy utilization to 85%.

The limits are highly dependent on the system design.



Heating Regions in China.

Technical Features of a Typical Chinese District Heating System

1. Some of the main features of a typical large Chinese district heating system are illustrated at Fig. 1 (at page 2).

Heat Production

2. In a typical Chinese district heating system only one heat producing unit will supply heat for the entire network. However, at some locations the co-generation as well as the heat only boilers supply heat to the system operated as a two stage heating of the district heating water as the co-generation unit and heat only boilers are located at the same site. Usually, the capacity of the heat producing unit will correspond to the maximum heat load requirement of the system and no spare capacity is installed (in case of break down).

3. The cold return water entering the heat producing unit is heated in the heat exchanger in a co-generation plant. The water flow is created by the main circulation pumps located at the heat production unit. The circulation pumps are typically the fixed speed type. Auxiliary equipment is also located at the heat producing unit: Pressure control equipment, water replenishment equipment and water treatment equipment.

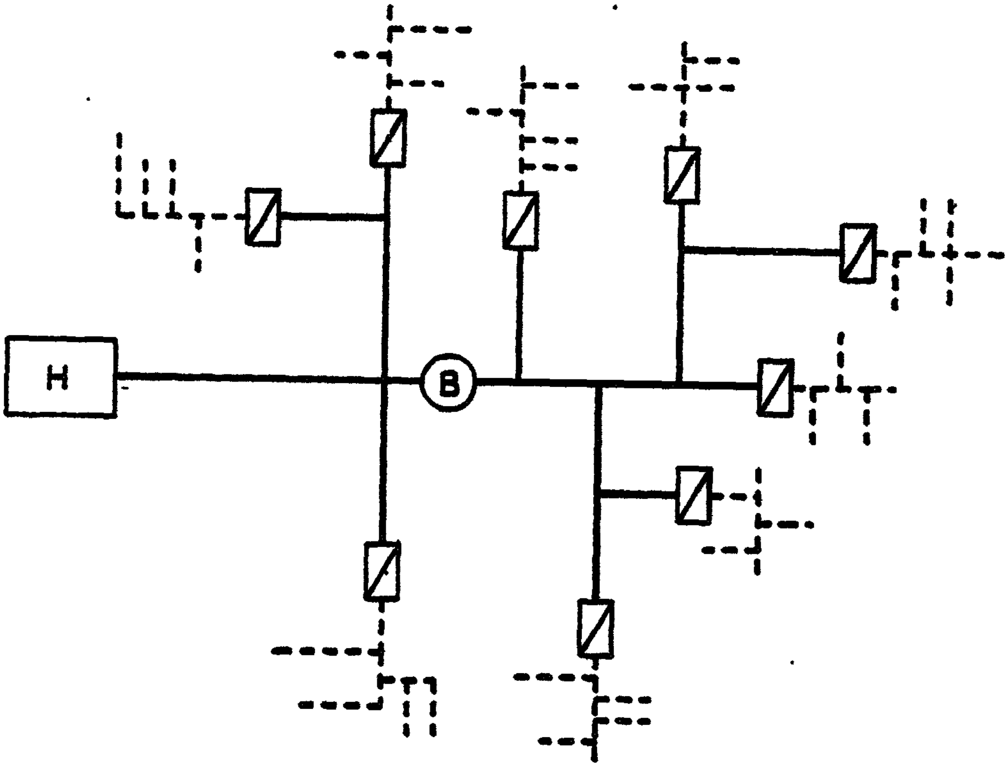
Pipe Network

4. The water is circulated through the pipe network (the transmission network and/or mains) to a number of substations. A number of different pipe network constructions are used. For very large pipes (Typical DN 800 mm and larger), the district heating pipes are insulated steel pipes located over ground. For smaller pipes (but examples of very large pipes are also found), the pipe construction is underground concrete ducts with insulated steel pipes. Small pipes (typically DN 300 mm or smaller) are typically insulated steel pipes in underground brick ducts. Some pre-insulated steel pipes (Chinese manufacture) are also found among the smaller pipe dimensions, but are not very common in the district heating pipe networks. The typical pipe in duct construction is illustrated in Figure 2 (page 3). For comparison, the normal western pre-insulated district heating pipes are also shown.

Booster Pumps

5. In big transmission networks, the required design pressure (and the required pump head of main pumps) is decreased by application of booster pumps. Usually, return booster pumps are utilized. The booster pumps are of the fixed speed type.

FIGURE 1



LEGEND:

H HEAT PRODUCTION

B BOOSTER PUMP

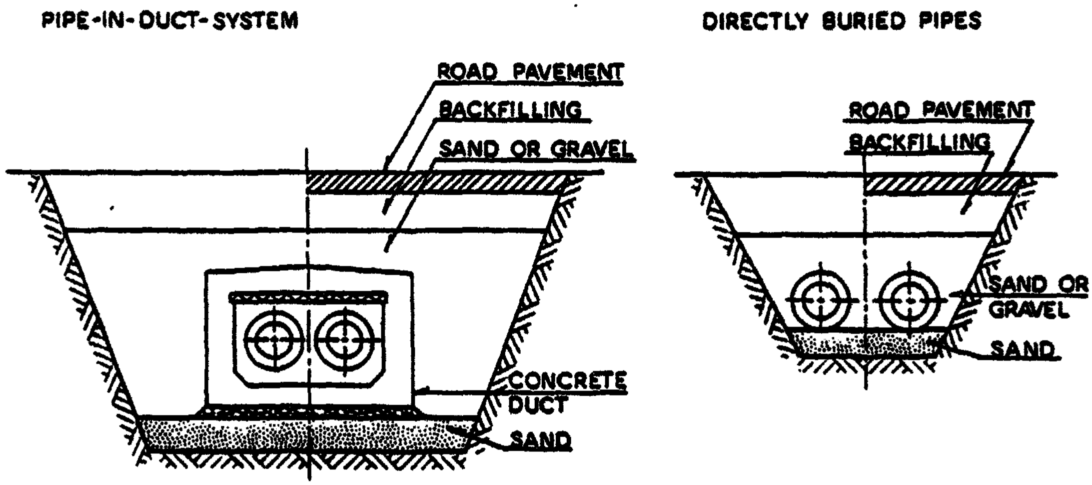
SUBSTATION

TRANSMISSION PIPE

DISTRIBUTION PIPE

Main features of a typical large Chinese District Heating System (co-generation).

FIGURE 2



Pipe in concrete duct system and direct buried (pre-insulated) pipe system.

Substations

6. Several different substation designs are utilized in Chinese district heating systems. Two main substation designs are:

- The direct connection type.
- The indirect connection type.

In the direct connection, the district heating water in the main pipe network and the water in the consumer installations (water in the radiators of the buildings) are not hydraulicly separated. Normally, the supply temperature to the consumer installations can be controlled by mixing the supply water with (cold) return water by operation of a mixing pump and manual valves. In a number of direct connection substations, the mixing pump also serves as a return booster pump (substations located in the areas supplied with very little differential pressure from the main pumps).

7. In the indirect connection type the district heating water in the main pipe network and the water in the consumer installations are hydraulically separated through utilization of heat exchangers. The supply temperature to the consumer installations can be controlled by the water flow on the primary side of the heat exchanger (side connected to the main pipe network). In some substations, the control of the primary water flow is performed by manual control, but also automatic control valves are found in Chinese systems.

Consumer Installation

8. The typical consumer installation is supplied from the distribution network. A set of main valves are located where the pipes enter the building. The supply water is normally led to the top of the building and supplied to a number of radiator installations. The typical radiator installation is of the single string type with no manual nor automatic control valves applied. As the hot supply water passes the individual radiators it cools down (heating the room). To compensate for the cooler water entering the radiators in the bottom apartments, these radiators are often somewhat larger than the radiators in the top apartments.

9. Consumer installations are not equipped with valves or other means of heat load control. Consequently, if the indoor temperature exceeds a desirable level, the only option for the consumer is to open the window.

Heat Load Control

10. In the normal Chinese district heating system the heat load is controlled by the supply temperature. Several Chinese district heating systems are designed as high temperature hot water systems using (maximum) supply temperatures of 150 C, but also hot water systems operating at supply temperatures less than 120 C are found. (In Shenyang the maximum supply temperature is as low as 68 C).

11. The water flow in the system (main system and consumer installations) is maintained constant throughout the heating period, and the supply temperature from the heat producing unit is controlled according to the outdoor temperature. Adjustments are performed by manual adjustment of valves at the substations, but usually those adjustments are only done at the beginning of the heating season.

Block Heating

12. In block heating systems neither transmission network nor substations are found, but the substations are substituted by coal-fired boiler houses with coal-fired chain grate boilers. At each booster house, there will be auxiliary equipment such as circulation pumps, pressure control equipment, water replenishment equipment, water treatment equipment, etc. The above remarks on consumer installations, heat load control and pipe network (small dimensions) are also valid for block heating systems.

Institutional Aspects of DH/CHP

13. In China, there are several institutional constraints regarding the development and operation of district heating, especially district heating with co-generation.

14. In the typical large district heating system, the heat is generated at a co-generation unit (power plant). Usually, the power plant is operated by an electricity company supplying the co-generated heat to a district heating company. The district heating company will be in charge of the transmission of the hot water to a number of substations. The hot water is supplied to the buildings through a distribution network connected to the substations. Usually, the owners of the buildings will be in charge of the operation of the distribution network, the secondary side of the substation and the operation of the internal systems in the buildings. Typical owners of buildings are factories, institutions, etc.

15. One of the institutional problems in respect of co-generation is the fact that the electric power production is somewhat derated caused by the production of hot water (or steam). The heat supplied by the co-generation unit to the district heating company is usually supplied at a loss to the electricity company. This situation and the present shortage of electric power in China create an incentive for the electricity companies to give priority to electric power production and not to supply the required heat to the district heating companies.

16. In the normal district heating system with co-generation several major parts of the district heating system are constructed and operated by the power plant. Such equipment usually comprises main pumps, equipment for pressure control and water replenishment as well as equipment for heat load control. This situation is caused by several reasons, the main reason being the location of the equipment at the power plant and the requirement for coordination of the power plant boilers, turbine operation and heat production.

17. If the technical standard of the district heating system is enhanced through introduction of automatic controls in the district heating system, this will also require modification of the equipment at the power plant, such as application of speed control for main pumps and modification of the heat load control concept. Such modifications of the district heating systems will require investments by both the district heating company and the electricity company.

18. In the present situation, where the power plant supplies heat (with a loss), it is very likely that investments in the district heating part of the power plant will have very low priority (from the electricity Companies' point of view); hence, this will impose a restriction on the development of district heating systems.

Analysis of Central Heating Options

Assumptions

A. Heat supply area & coal quality

Supply area	6 billion m^2 floor area
No. of households	120,000
Apartment size	$50m^2$
Coal quality	5000 kcal/kg
Ash content	25%
Sulfur content	1.2%

B. Construction Build-up

- District heating part of co-generation plant:	3 years (33%, 33%, 33%)
- District heating transmission network and substations:	3 years (40%, 40%, 20%)
- Consumer installations:	2 years (50%, 50%)
- Heat only boilers :	3 years (30%, 40%, 30%)
- District heating: distribution network	3 years (40%, 40%, 20%)
- Dispresed boilers (DB)	2 years (50%, 50%)

C. Equipment life — 20 years

(No assumptions are made regarding renewal of small boiler or of DH transmission/distribution networks. In both cases, after 15 years, some replacement costs may be incurred.)

D. Conversion Factors

Investments	Factor
1. DH/HCP	
- Cogen unit	1.7
- Transmission	1.2
2. DH/Heat only	1.7
3. Dispersed boilers	1.7
4. Distribution	1.8
5. Consumer installations	1.2

Operating Costs	
1. Labor	
- DH/CHP and DH/heat only	1.2
- Dispersed boilers	1.0
2. Maintenance	1.2
3. Coal	100, 150 and 200 yuan/ton

4. Power Costs

		Capacity Y/kW	Energy Y/kWh	All-in Y/kWh	Conv. Factor	CHP Plant Derating	DH grid Use
						------Y million----	
Financial		72	0.055	0.091	1.0	12.1	1.9
Economic Shortage cost		0	0.500	0.500	5.5	66.6	10.5
Economic Supply cost							
with coal at Y/ton:	100	475	0.052	0.280	3.2	38.6	6.1
	150	475	0.078	0.316	3.5	42.0	6.6
	200	475	0.104	0.341	3.8	45.5	7.2

NOTES:
Financial price of power as per published tariff for large industry

Economic price after the year 2000:
based on the capacity and fixed O&M costs and heat rate of a 300 MW unit

Economic price until the year 2000:
based on the cost of capacity underutilisation incurred by low priority industrial users , i.e 25% of their value added per kWh.

Construction and Operating Costs
(Financial Costs)

I. Dispersed Boilers

Assumptions:

Design Heat Period	60 kcal/h pr m^2 floor area
Heat Supply Period	75% of heating period, on-off operat.
Design Heat Demand	0.12 mill kcal/m^2 pr season
Average Boiler Rating	0.33 mill kcal/h
Boiler Efficiency	55%
Staff pr Boiler	3
Electric Power Consumption	3.50 kWh/m^2 pr season (FD-fans, etc)
Coal consumption	261,818 tons/season
Construction Cost (boilers)	150000 yuan pr mill kcal/h
Const. Cost (building inst)	15 yuan pr m^2 floor area
Labour	200 yuan pr worker pr year
Labour Overhead	1400 yuan pr worker pr year
Maint. & Materials (building)	2% of const. cost (annual)
Maint. & Materials (boiler)	5% of const. cost (annual)

Calculations:

Tot Des. Heat Load (build.)	360 mill kcal/h
Tot. Inst. Boiler Cap.	480 mill kcal/h
Total Heat Supplied	720 billion kcal/season
Total Coal Consumption	261818 tons/season
Consumption pr. m^2	44 kg/m^2 pr season
Number of Boilers	1455
Total Number of Staff	4364

Construction Costs:

Boilers etc	72 mill yuan
Installations	90 mill yuan
Total	162 yuan /m^2
Total Const. Cost pr m^2	27 yuan /m^2

Itemized Operating Costs			M Yuan pr year	Yuan pr M kcal
Steam Coal	281818 tons/season	100 yuan/t	28.182	38.39
Electric	21 Gwh/season	0.091 y/kWh	1.910	2.65
Labour	4364	2000 yuan/year	8.727	12.12
Labour overhead	4364	1400 yuan/year	6.109	8.48
Maint. & Mat., bldg.	2% of 90 Mill Yuan		1.800	2.50
Maint. & Mat., boilers	5% of 72 Mill Yuan		3.600	5.00

Emission Factors

TSP	3.50 kg/ton coal * ash content (%)
TSP removal	80%
SO_2	19 kg/ton coal * Sulphur content (%)
CO	1 kg/ton coal
HC	0.50 kg/ton coal
NO_x	7.50 kg/ton coal

Construction and Operating Costs
(Financial Costs)

II DH/Heat Only (Block Heating)

Assumptions:

Supply Area	6 mill m^2 floor area
Design Heat Loan	60 kcal/h pr m^2 floor area
Heat Supply Period	100 % of heating period
Design Heat Demand	0.12 mill kcal/m^2 pr season
Average Boiler Rating	8.00 mill kcal/h
Boiler Efficiency	70%
Staff pr Boiler	30
Distribution Network Loss	8%
Electric Power Consumption	3.50 kWh/m^2 pr season (FD-fans,etc)
Coal Consumption	223,602 tons/season
Const. Cost Boiler House	250000 yuan pr mill kcal/h
Const. Cost Distb. Network	4 yuan pr m^2 floor area
Const. Cost Build. Install.	15 yuan pr m^2 floor area
Labour	2000 yuan pr worker pr year
Labour Overhead	1400 yuan pr worker pr year
Maint. & Materials (bldg.)	2% of const. cost (annual)
Maint. & Materials (distr.)	3% of const. cost (annual)
Maint. & Materials (boilers)	3% of const. cost (annual)

Calculations:

Des. Heat Load (Boilers)	391 mill kcal/h (incl. dist. loss)
Des. Heat Load (Supplied)	360 mill kcal/h (supplied to build.)
Total Heat Supplied	720 billion kcal/season
Total Coal Consumption	228602 tons/season
Consumption pr. m^2	37 kg/m^2 pr season
Number of Boilers	49
Total Number of Staff	1467
Total Elect. Power Cons.	21 GWh/season

Construction and Operating Costs
(Financial Costs)

II DH/Heat Only (Block Heating)

Assumptions:	
Supply Area	6 mill m^2 floor area
Design Heat Loan	60 kcal/h pr m^2 floor area
Heat Supply Period	100 % of heating period
Design Heat Demand	0.12 mill kcal/m^2 pr season
Average Boiler Rating	8.00 mill kcal/h
Boiler Efficiency	70%
Staff pr Boiler	30
Distribution Network Loss	8%
Electric Power Consumption	3.50 kWh/m^2 pr season (FD-fans,etc)
Coal Consumption	228,602 tons/season
Const. Cost Boiler House	250000 yuan pr mill kcal/h
Const. Cost Distb. Network	4 yuan pr m^2 floor area
Const. Cost Build. Install.	15 yuan pr m^2 floor area
Labour	2000 yuan pr worker pr year
Labour Overhead	1400 yuan pr worker pr year
Maint. & Materials (bldg.)	2% of const. cost (annual)
Maint. & Materials (distr.)	3% of const. cost (annual)
Maint. & Materials (boilers)	3% of const. cost (annual)
Calculations:	
Des. Heat Load (Boilers)	391 mill kcal/h (incl. dist. loss)
Des. Heat Load (Supplied)	360 mill kcal/h (supplied to build.)
Total Heat Supplied	720 billion kcal/season
Total Coal Consumption	228602 tons/season
Consumption pr. m^2	37 kg/m^2 pr season
Number of Boilers	49
Total Number of Staff	1467
Total Elect. Power Cons.	21 GWh/season

Construction and Operating Costs
(Financial Costs)

III. District Heating with Co-Generation (DH/CHP)

Assumptions:	
Supply Area	6 mill m^2 floor area
Design Heat Load	60 kcal/h pr m^2 floor area
Design Heat Demand	0.12 mill kcal/m^2 pr season
Co-Gen Unit Rating (heat)	360 mill kcal/h (excl. losses)
Boiler Eff. (CHP unit)	85% (not used in this model)
Staff	1500
Distribution Network Loss	8%
Transmission Network Loss	4%
Electric Power Consumption	3.50 kWh/m^2 pr season (pumps etc)
Coal Consumption	69,000 tons (consumption for derated electric power production
Con. Cost CHP Unit (tot)	1875 yuan/kW (elect.), summer prod.
Con. Cost DH part of Co-Gen	10%
Const. Cost Trans. Network	11 Yuan pr m^2 floor area
Const. Cost Substations	4 Yuan pr m^2 floor area
Const. Cost Distb. Network	4 Yuan pr m^2 floor area
Const. Cost Build. Install.	15 Yuan pr m^2 floor area
Power Plant Data	
Cv- Valu (extraction line)	0.14 MW (elec) MJ pr sec (Heat)
Cm- Value (back pres. line)	0.50 MW (elec) MJ pr sec (Heat)
Effic. Power. Prod	33% (no heat extraction) (520 grams coal pr kWh)
Co-Generation Period	4.50 month/year

Operating Cost

Labour	2000 yuan pr worker pr year
Labour overhead	1400 yuan pr worker pr year
Maint. & materials(bldg	2% of const. cost (annual)
Maint. & materials (distr)	8% of const. cost (annual)
Maint. & materials (trans)	3% of const. cost (annual
Maint. & materials (co-gen unit)	8% of const. cost (annual)
Capital charges	15% of const. cost (annual)

Calculations:

T. Des. Heat Loan CHP	408 mill kcal/h heat
T. Des. Heat Load (Supplied)	380 mill kcal/h
Total Heat Supplied	720 billion kcal/season
Total Heat Produce	820 billion kcal/season
Average Winter Load	252 billion kcal/season
Req. Size of CHP Plant	302 MW (elec) output, summer operation
Maximum Derating of Power Plant	66 MW (elec) output, average winter 41/MW
Average Winter Power Derating	41/MW
Elec. Power Prod. Derating	132 GWh/year electric power production
Elect. Power Output, Winter	261 MW (elec) output, average winter
Coal Cons., Derated Power	69000 ton coal per season
Coal Consumption pr m^2	11.5 kg/m^2 floor area pr season

Power Plant Data

	Summer Max. elec.	%	Winter Max. Heat	%	Winter Average	%
Elec. Power (MW e.)	302	33	236	26	261	28
Heat (MJ/sec)	0	0	472	51	292	32
Loss (MJ/sec)	613	67	207	23	362	40
Total	915	100	915	100	915	100

Number of CHP Units	1
Total Number of Staff	1500
Total Elect. Power Cons.	21 GWh/season

Construction Cost-Power Plant	566 mill yuan
Heat Exchangers	89 mill yuan
Const. Cost. Trans. Network	66 mill yuan
Const. Cost. Substations	24 mill yuan
Const. Cost, Dist. Network	24 mill yuan
Const. Cost, Build. Install	90 mill yuan
Total Construction Cost	293 mill yuan
Total Const. Cost pr m^2	49 yuan/m^2

Itemized Operating Cost			M yuan pr year	Yuan pr M kcal
Val. of derating	182 Gwh	0.066 yuan.kWh	12.012	16.68
Electric	21 Gwh/season	0.066 yuan/kWh	3.570	4.96
Labour	1500	2000 yuan/year	3.000	4.17
Labour overhead	1500	1400 yuan/year	2.100	2.92
Maint., bldg.	2% of 90 mill yuan		1.800	2.50
Maint. distr.	3% of 24 mill yuan		0.720	1.00
Maint. trans.	3% of 66 mill yuan		1.980	2.75
Maint. subs.	3% of 24 mill yuan		0.720	1.00
Maint. heat exch.	3% of 89 mill yuan		5.621	7.81

Emission Factors

TSP	3.50 kg/ton coal * ash content (2%)
TSP removal	99% - ESP
SO_2	19 kg/ton coal * Sulphur content (%)
CO	0.50 kg/ton coal
HC	0.15 kg/ton coal
NO_x	9.00 kg/ton coal

Economic Analysis of Space Heating Options
Base Case Financial Prices
(Y million)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Y/Gcal
Heat demand (billion kcal)	0	0	0	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	
INVESTMENTS																								
DH/Cogeneration Heat & Power (CHP)																								
Cogeneration unit	189.0	189.0	189.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Transmission	65.0	65.0	49.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
DH/Heat only	29.4	39.2	29.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Distribution	9.6	9.6	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Dispersed boilers	0.0	36.0	36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Consumer installation	0.0	0.0	90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
FIXED O&M COSTS																								
Maintenance:																								
Cogeneration unit				17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	
Transmission				5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	
DH/Heat only				2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	
Distribution				0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	
Dispersed boilers				3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	
Consumer installation				1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
Labor:																								
DH/CHP				5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	
DH/Heat only				5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
Dispersed boilers				14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	
Electricity																								
Power derating of CHP				12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	16.8
Electricity use				1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.6
AGGREGATED COSTS																								
Dispersed Boilers																								
Investment	0.0	36.0	126.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.0
Fixed O & M	0.0	0.0	0.0	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	30.7
Coal Use	0.0	0.0	0.0	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	36.4
Total	0.0	36.0	126.0	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	94.1
Block Heating																								
Investment	39.0	48.8	124.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.7
Fixed O & M	0.0	0.0	0.0	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	17.1
Coal Use	0.0	0.0	0.0	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	31.1
Total	39.0	48.8	124.2	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7	84.9
DH/CHP: Heat																								
Investment	74.6	74.6	143.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	51.6
Fixed O & M	0.0	0.0	0.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	18.1
Electricity	0.0	0.0	0.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	19.4
Total	74.6	74.6	143.8	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	89.1
Heat Benefits				67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	94.1
DH/CHP: Power																								
Investment	189.0	189.0	189.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	102.1
Fixed O & M	0.0	0.0	0.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	23.6
Coal	0.0	0.0	0.0	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5	120.1
Total	189.0	189.0	189.0	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	103.5	245.6
Power Benefits				113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	113.1	37.7
DH/CHP Net Cash-Flow	-263.6	-263.6	-332.8	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4	-203.1

IRR= 1.4%

NOTES:

Dispersed Boilers	Investment = Boilers + Consumer Installation	Fixed O & M = Maintenance & Labor for Boilers + Consumer Installation + Electricity use (FD-fans,etc)
DH/Heat only boilers	Investment = Boilers + Distribution + Consumer Installation	Fixed O & M = Maintenance & Labor for Boilers + Distribution + Consumer Installation + Electricity use (FD-fans,etc)
DH/CHP: heat	Investment = Transmission + Distribution + Consumer Installation	Fixed O & M = Maintenance & Labor for Transmission + Distribution + Consumer Installation; Electricity = Power Derating for CHP + Electricity use
DH/CHP: Power	Investment = Cogeneration Unit	Fixed O & M = Maintenance & Labor for Cogeneration Unit

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Economic Analysis of Space Heating Options
Base Case   Economic Prices
(Y million)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011		
Heat demand (billion kcal)	0	0	0	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720		
at Financial Prices																									
INVESTMENTS																									Conv. Factor
DH/Cogeneration Heat & Power (CHP)																									
Cogen unit	189.0	189.0	189.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Transmission	65.0	65.0	49.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.2
DH/Heat only	29.4	39.2	29.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Distribution	9.6	9.6	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.8
Dispersed boilers	0.0	86.0	86.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Consumer install.	0.0	0.0	90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.2
FIXED O&M COSTS																									
Maintenance:																									
Cogen unit				17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0		1.2
Transmission				5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4		1.2
DH/Heat only				2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9		1.2
Distribution				0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7		1.2
Dispersed boilers				3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6		1.2
Consumer install.				1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8		1.2
Labor:																									
DH/CHP				5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1		1.2
DH/Heat only				5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0		1.2
Dispersed boilers				14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8		1.0
Electricity — at Economic prices																								Y/Gcal	
Power derating of CHP				66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	79.9	4.8
Electricity use				10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	12.6	4.8
AGGREGATED COSTS																									
at Economic prices																									
Dispersed Boilers																									
Investment	0.0	51.4	180.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	38.6	1.4
Fixed O & M	0.0	0.0	0.0	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	1.4
Coal Use	0.0	0.0	0.0	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	36.4	1.0
Total	0.0	51.4	180.0	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	117.1	1.2
Block Heating																									
Investment	59.0	73.8	187.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.5	1.5
Fixed O & M	0.0	0.0	0.0	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	29.9	1.8
Coal Use	0.0	0.0	0.0	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	31.1	1.0
Total	59.0	73.8	187.8	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	116.6	1.4
DH/CHP: Heat																									
Investment	93.3	93.3	179.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	64.5	1.3
Fixed O & M	0.0	0.0	0.0	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	21.7	1.2
Electricity	0.0	0.0	0.0	77.1	77.1	77.1	77.1	77.1	77.1	77.1	77.1	77.1	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	92.5	4.8
Total	93.3	93.3	179.9	92.7	92.7	92.7	92.7	92.7	92.7	92.7	92.7	92.7	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	178.7	2.0

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Economic Analysis of Space Heating Options
Medium Cost Coal Economic Prices
(Y million)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Y/Gcal	Conv. Factor
Heat demand (billion kcal)	0	0	0	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720		
	at Financial Prices																								
INVESTMENTS																									
DH/Cogeneration Heat & Power (CHP)																									
Cogen unit	189.0	189.0	189.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Transmission	65.0	65.0	49.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.2
DH/Heat only	29.4	39.2	29.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Distribution	9.6	9.6	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.8
Dispersed boilers	0.0	36.0	36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Consumer install.	0.0	0.0	90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.2
FIXED O&M COSTS																									
Maintenance:																									
Cogen unit				17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0		1.2
Transmission				5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4		1.2
DH/Heat only				2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9		1.2
Distribution				0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7		1.2
Dispersed boilers				3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6		1.2
Consumer install.				1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8		1.2
Labor:																									
DH/CHP				5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1		1.2
DH/Heat only				5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0		1.2
Dispersed boilers				14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8		1.0
Electricity	at Economic prices																							Y/Gcal	
Power derating of CHP				66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	81.4	4.9
Electricity use				10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	12.8	4.9
AGGREGATED COSTS																									
	at Economic prices																								
Dispersed Boilers																									
Investment	0.0	51.4	180.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	38.6	1.4
Fixed O & M	0.0	0.0	0.0	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	1.4
Coal Use	0.0	0.0	0.0	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	54.6	1.0
Total	0.0	51.4	180.0	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	135.6	1.2
Block Heating																									
Investment	59.0	73.8	187.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.5	1.5
Fixed O & M	0.0	0.0	0.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	30.2	1.8
Coal Use	0.0	0.0	0.0	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	46.7	1.0
Total	59.0	73.8	187.8	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	70.6	132.3	1.3
DH/CHP: Heat																									
Investment	93.3	93.3	179.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	64.5	1.3
Fixed O & M	0.0	0.0	0.0	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	21.7	1.2
Electricity	0.0	0.0	0.0	77.1	77.1	77.1	77.1	77.1	77.1	77.1	77.1	77.1	48.6	48.6	48.6	48.6	48.6	48.6	48.6	48.6	48.6	48.6	48.6	94.3	4.9
Total	93.3	93.3	179.9	92.7	92.7	92.7	92.7	92.7	92.7	92.7	92.7	92.7	64.2	64.2	64.2	64.2	64.2	64.2	64.2	64.2	64.2	64.2	64.2	180.5	2.0

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Economic Analysis of Space Heating Options
High Cost Coal Economic Prices
(Y million)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011		
Heat demand (billion kcal)	0	0	0	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720		
											at Financial Prices														
INVESTMENTS																									Conv. Factor
DH/Cogeneration Heat & Power (CHP)																									
Cogen unit	189.0	189.0	189.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Transmission	65.0	65.0	49.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.2
DH/Heat only	29.4	39.2	29.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Distribution	9.6	9.6	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.8
Dispersed boilers	0.0	36.0	36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Consumer install.	0.0	0.0	90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.2
FIXED O&M COSTS																									
Maintenance:																									
Cogen unit				17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0		1.2
Transmission				5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4		1.2
DH/Heat only				2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9		1.2
Distribution				0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7		1.2
Dispersed boilers				3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6		1.2
Consumer install.				1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8		1.2
Labor:																									
DH/CHP				5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1		1.2
DH/Heat only				5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0		1.2
Dispersed boilers				14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8		1.0
																								Y/Gcal	
Electricity											at Economic prices														
Power derating of CHP				66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	83.0	5.0
Electricity use				10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	13.1	5.0
AGGREGATED COSTS																									
											at Economic prices														
Dispersed Boilers																									
Investment	0.0	51.4	180.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.6	1.4
Fixed O & M	0.0	0.0	0.0	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	1.4
Coal Use	0.0	0.0	0.0	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	72.8	1.0
Total	0.0	51.4	180.0	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1	154.0	1.2
Block Heating																									
Investment	59.0	73.8	187.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.5	1.5
Fixed O & M	0.0	0.0	0.0	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	37.3	30.4	1.8
Coal Use	0.0	0.0	0.0	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	62.2	1.0
Total	59.0	73.8	187.8	[illegible]	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	82.1	148.2	1.3
DH/CHP: Heat																									
Investment	93.3	93.3	179.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.5	1.3
Fixed O & M	0.0	0.0	0.0	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	21.7	1.2
Electricity	0.0	0.0	0.0	77.1	77.1	77.1	77.1	77.1	77.1	77.1	77.1	77.1	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	96.1	5.0
Total	93.3	93.3	179 9	92.7	92.7	92.7	92.7	92.7	92.7	92.7	92.7	92.7	68.3	68.3	68.3	68.3	68.3	68.3	68.3	68.3	68.3	68.3	68.3	182.3	2.1

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Economic Analysis of Space Heating Options
Slow Hook up Economic Prices
(Y million)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011		
Heat demand (billion kcal)	0	0	0	120	240	300	480	600	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720		
----at Financial Prices ----																									
INVESTMENTS																									Conv. Factor
DH/Cogeneration Heat & Power (CHP)																									
Cogen unit	189.0	189.0	189.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Transmission	65.0	65.0	49.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.2
DH/Heat only	29.4	39.2	29.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Distribution	9.6	9.6	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.8
Dispersed boilers	0.0	36.0	36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Consumer install.	0.0	0.0	15.0	15.0	15.0	15.0	15.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.2
FIXED O&M COSTS																									
Maintenance:																									
Cogen unit				17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0		1.2
Transmission				5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4		1.2
DH/Heat only				2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9		1.2
Distribution				0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7		1.2
Dispersed boilers				3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6		1.2
Consumer install.				0.3	0.6	0.9	1.2	1.5	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8		1.2
Labor:																									
DH/CHP				5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1		1.2
DH/Heat only				5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0		1.2
Dispersed boilers				14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8		1.0
																								Y/Gcal	
Electricity ----at Economic prices ----																									
Power derating of CHP				11.1	22.2	33.3	44.4	55.5	66.6	66.6	66.6	66.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	76.8	4.6
Electricity use				0.4	2.0	3.7	5.4	7.1	8.8	10.5	10.5	10.5	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	10.7	4.1
AGGREGATED COSTS																									
----at Economic prices ----																									
Dispersed Boilers																									
Investment	0.0	52.4	74.3	21.8	15.0	15.0	15.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.3	1.5
Fixed O & M	0.0	0.0	0.0	24.0	26.3	28.8	31.4	33.9	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	48.8	1.3
Coal Use	0.0	0.0	0.0	4.4	8.7	13.1	17.5	21.8	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	36.7	1.0
Total	0.0	52.4	74.3	50.2	50.0	56.9	63.9	70.7	62.6	62.6	62.6	62.6	62.6	62.6	62.6	62.6	62.6	62.6	62.6	62.6	62.6	62.6	62.6	131.9	1.2
Block Heating																									
Investment	60.0	75.1	75.7	23.1	15.0	15.0	15.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	68.7	1.5
Fixed O & M	0.0	0.0	0.0	14.5	17.5	20.6	23.7	26.8	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	32.7	1.6
Coal Use	0.0	0.0	0.0	3.7	7.5	11.2	14.9	18.6	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	31.4	1.0
Total	60.0	75.1	75.7	41.3	40.0	46.8	53.8	60.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	132.8	1.4
DH/CHP: Heat																									
Investment	93.6	93.6	86.3	18.8	18.8	18.8	18.8	18.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.7	1.3
Fixed O & M	0.0	0.0	0.0	13.8	14.2	14.5	14.9	15.2	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	27.7	1.2
Electricity	0.0	0.0	0.0	11.5	24.2	37.0	49.8	62.6	75.4	77.1	77.1	77.1	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	67.4	4.5
Total	93.6	93.6	86.3	44.1	57.2	70.3	83.5	96.7	91.0	92.7	92.7	92.7	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	195.6	1.8

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Economic Analysis of Space Heating Options
High Investmt. Economic Prices
(Y million)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Y/Gcal	Conv Factor
Hea demand (bi ion kcal)	0	0	0	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720		
at Financial Prices																									
INVESTMENTS																									
DH/Cogeneration Heat & Power (CHP)																									
Cogen unit	227.0	227.0	227.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1 7
Transmission	78.0	78.0	59.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1 2
DH/Heat only	35.3	47.0	35.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1 7
Distribution	11.5	11.5	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1 8
Dispersed boilers	0.0	43.2	43.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.7
Consumer install.	0.0	0.0	108.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.2
FIXED O&M COSTS																									
Maintenance:																									
Cogen unit				17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0		1.2
Transmission				5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4		1.2
DH/Heat only				2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9		1 2
Distribution				0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7		1.2
Dispersed boilers				3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6		1 2
Consumer install.				1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8		1.2
Labor:																									
DH/CHP				5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1		1.2
DH/Heat only				5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0		1.2
Dispersed boilers				14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8		1.0
Electricity — at Economic prices																								Y/Gcal	
Power derating				66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	79.9	4.8
Electricity use				10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	12.6	4.8
AGGREGATED COSTS																									
at Economic prices																									
Dispersed Boilers																									
Investment	0.0	61.7	216.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.3	1.4
Fixed O & M	0.0	0.0	0.0	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	1.4
Coal Use	0.0	0.0	0.0	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	36.4	1.0
Total	0.0	61.7	216.0	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	124.9	1.3
Block Heating																									
Investment	70.8	88.5	225.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.6	1.5
Fixed O & M	0.0	0.0	0.0	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	29.9	1.8
Coal Use	0.0	0.0	0.0	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	31.1	1.0
Total	70.8	88.5	225.4	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	127.7	1.4
DH/CHP: Heat																									
Investment	112.0	112.0	216.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	77.5	1.3
Fixed O & M	0.0	0.0	0.0	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	21.7	1.2
Electricity	0.0	0.0	0.0	77.1	77.1	77.1	77.1	77.1	77.1	77.1	77.1	77.1	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	92.5	4.8
Total	112.0	112.0	216.2	92.7	92.7	92.7	92.7	92.7	92.7	92.7	92.7	92.7	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	60.3	191.7	1.9

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Building Insulation 1/

Background

1. The housing stock in China is rising rapidly. In the next ten years, 1.2-1.5 billion m^2 of heated residential housing is expected to be constructed. In Beijing alone, residential building construction is said to be increasing by 5 million m^2 of floor area per year (about 90,000 apartments).2/ New residential buildings are of two types: (i) mid rise, 6-storey buildings; and (ii) high rise, 12-16 storey buildings. They are built according to standard designs using brick and concrete construction. The varied climate in different regions of the country affect building features. Costs vary from Y 150-180/m^2 for mid rise to Y 300-450/m^2 for high rise buildings.3/

Introduction of Standards

2. In 1986, the State Planning Commission issued, on a trial basis, a general design standard for constructing better insulated housing.4/ The standard calls for reducing energy consumption in residences by 30 percent, but limits the additional building investment to $\leq$5 percent. It is performance oriented; values for the air tightness of windows and the overall heat transfer coefficient of building components are specified. The standard is to act as a model for cities in creating their own local standards. Those which have done so include: Beijing, Tianjin, Xian, and provinces of Liaoning, Jilin, Heilongjiang and Shanxi. But the standards still remain goals; only a few buildings have incorporated them, primarily in demonstration projects.

Status of Building Research

3. There is a dedicated body of researchers working on building-related energy conservation measures. To convince authorities and overcome the sensitivity over up-front costs, people involved in building research have been focusing on approaches that reduce costs. Research has been undertaken in several cities, notably Harbin, Beijing, Wuxi, and Zhengzhou (Henan province). The results of their work are promising, but further data is needed on differ-

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1/ This annex is based largely on work of B. Adamson.

2/ Gross floor area is 56 m^2; actual apartment area is 45-50 m^2.

3/ Attachment 1 shows design data for mid rise apartment buildings in some cities.

4/ There are reports that an even higher trial standard is to be announced in 1990, calling for a 50 percent reduction.

ent types of buildings in each region.4/ Moreover, an important problem is the criteria for investment decision-making. Using simply the investment cost as a cut-off point does not give weight to the savings from heat loss reductions, which will vary according to the type of investment, the extent of heat losses, and the cost of the particular heat supply. Moreover, economic costs of resources and energy are not normally used in valuing the costs and benefits of conservation measures.

Problems of Implementation

4. Researchers indicate that it is very hard to convince architects and building contractors to incorporate insulation. This has been a problem in most countries because of contractor resistance to new practices and interest in keeping up-front costs low. In China, the shortage of materials and the need for housing magnifies these traditional problems. There is much stronger interest in building more apartments than better insulated housing when investment funds are limited and the costs of building materials (brick, rock-wool, perlite and gypsum) are rising. The focus is on the up-front costs, not the total savings which could be realized from a given investment.

5. Another factor is that the present system of heating charges provides no incentive to building owners to invest in energy saving modifications.5/ Each building is charged for heating according to the floor area, not according to actual heat consumed. In fact, most buildings do not have metering devices. As a result, there are no gains to individual building owners--but there is a funding burden--in making larger up-front investments in order to have more efficient buildings.

Potential Conservation Measures

6. Major improvements in conservation of energy could be made through investments in insulation to reduce unintended ventilation. These include: better design and manufacture of windows; double glazing and sealing of windows; improved thermal insulation of walls and roofs; and use of passive solar

4/ For example, Beijing has had two demonstration projects involving buildings with an area totaling 4,000 m^2; according to the experts, heat losses were reduced by 30 percent, but costs were increased by 8 percent (vs. the 5 percent called for in the state regulations). In the Asian Games Village now being constructed, new designs and better insulation have been installed in many of the buildings. The seed money for these model buildings has been obtained from various government organizations. The researchers involved intend to measure the heat flow through buildings and estimate energy savings. They hope by these models to demonstrate and convince municipal authorities and others in charge of construction that better insulation can be achieved at low cost.

5/ Building owners are usually factories or enterprises which invest in housing for their employees. In Beijing, the municipal government invests in buildings and then sells them to enterprises.

energy by southern orientation of windows with good solar transmission.6/ There also needs to be better control of the heat supply to buildings; reports are that the heat loss from heat piping systems is about 15 percent because of poor insulation and maintenance.7/ The techniques for achieving energy savings are well known and proven, although further experiments with available materials in China are necessary.

7. Window Improvements. The most important conservation measure concerns window features. Presently, single glazed, steel frame windows are used, which are not tightly sealed, with sometimes large cracks between the window and frame, allowing large heat losses. Air changes of 1.4 to 1.8 per hour are commonly estimated; some researchers have found air changes per hour (ach) of 2-3.5, which are very high. It is unnecessary to have over 0.8 ach.8/ The key improvements needed are:

(a) better quality control in manufacturing;

(b) more use of wood frames, as they fit more tightly and are easier to double pane;

(c) double glazing of windows; and

(d) better sealing of windows to reduce infiltration in cracks.

An important issue is the availability of wood for window frames, considered much more effective than steel frames. The shortage of wood in China is a constraint, but it may be possible to use hardwoods (rather than pine), which are more available. In Harbin and other very cold areas in the Northeast, wood frames are used in some buildings. In view of the greater efficiency, the potential for more extensive use of wood frames needs to be investigated further.9/ The potential for aluminum frames should also be considered.

8. Thermal Insulation of Walls and Roofs. Wall designs for apartments vary according to the locale and type of apartment building in China. Attachment 1 shows the construction characteristics of housing in several cities. In northern cities, the typical wall thickness is 370 mm to 470 mm. International and local research in China indicate that wall thicknesses could be

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6/ The winter climate in the north of China provides such opportunities to use solar energy.

7/ Lang Siwei, Institute of Air Conditioning, China Academy of Building Research, "Energy Use in Chinese Buildings," Proceedings of the Chinese-American Symposium on Energy Markets and the Future of Energy Demand, June 22-24, 1988, p. 14-2.

8/ For comparison, infiltration rates of US housing in the early 1980s were cited as ranging from 0.2 to 1.0 air changes per hour, with new homes averaging 0.7. Source: Huang, Y.J. and Rosenfeld, A., et al., "Energy Efficiency in Chinese Apartment Buildings: Parametric Analysis with the DOE-2.1A Computer Program," Lawrence Berkeley Lab, UC Berkeley: September 1983.

9/ Obviously, the pressure on wood supplies would have to be evaluated carefully.

reduced (thus saving money) by installing insulation in the cavities of walls, such as rockwool or perlite, and gypsum board in the interior wall.

9. Metering and Charge System. Heat meters should be installed, and consumption should be charged per kWh or GJ of heat used instead of per m^2 of floor area. This is the primary way to attract the attention of owners of buildings to the costs of heat supply. Moreover, good operation and maintenance of a building and its heating system depend on knowledge of how much heat is delivered to a building from the the boiler plant. Heat meters are necessary for measuring the heat supply.

10. The Manufacturing Infrastructure. Small collectives currently manufacture windows, and because of building demand they apparently make a lot of money, even though the quality is often poor. There is no differentiation of price for a quality product and, therefore, no incentive to improve quality control. Standards are published which factories are supposed to follow, but some factories cannot reach the standard (although some of these are now being retired). Only a few factories produce thermostatic valves and meters because these products are not widely used. Encouraging product development and quality control, therefore, must go hand in hand with implementation of building conservation measures.

Potential Investments Offering Heat Loss Reductions

11. New Buildings. The capital costs of improving windows and installing insulation materials over the growing housing stock are likely to be considerable. The benefits of improved insulation lie in the lower fuel consumption of households; implicit in this is a lower level of investment needed in energy production.10/ As the cost of the energy supply goes up, the savings from building insulation increase. For example, the high cost of heat supply from DH/CHP systems would imply larger benefits from insulation investments.

12. Calculating savings from building conservation measures depends on a variety of parameters and usually involves computer simulations which consider: existing and target temperatures, degree days and hours, the overall heat transfer coefficient of a building component (wall, roof, window etc.), the ventilation rate, position of the apartment, gross and net heating area, and combustion and distribution efficiency of the heat supply system. In this study, calculations were made by the JULOTTA program, a well-validated program in building research.11/

10/ The potential benefits are significant. For example, over the past 50 years, Sweden has been able to reduce the average heat requirement in residential apartments from 220 kWh/m^2 to 60-80 kWh/m^2.

11/ Kallblad, Sweden, 1986, used by Professor Bo Adamson, Department of Building Sciences, University of Lund, Sweden.

13. Calculations were made for a mid rise apartment building in Beijing and compared with other international and local studies.12/ "Heat saving costs" were calculated for some typical investments.13/ They were then compared with actual and estimated economic heat prices (the latter estimated in the range of 0.10-0.15Y/kWh). Investment costs were based on those available from Chinese authorities and represent a mixture of financial and economic costs. More work is needed to establish economic costs.

14. The following results are indicated from the modeling of cases based on the Beijing site:

(a) Investments in wood frame windows, double glazed and fitted tightly, will reduce heat losses by 35 percent at a heat saving cost of Y 0.02/kWh. The investment recovery time would be less than four years, assuming the heat price is Y 0.08/kWh. If the heat price is higher, the payback period will be even shorter.

(b) Reductions in wall thicknesses from 370 to 240 mm solid brick, by using 20 mm rockwool as insulation and 12 mm gypsum board on the inside of the wall--at no extra cost; heat transfers via the walls are reduced by 17.6 percent. Increasing the thickness of the rockwool insulation from 20 to 50 mm will reduce heat transfers by 40 percent more, at a heat saving cost of Y 0.04/kWh. Increasing the insulation further (from 50 to 70 mm) reduces heat transfers by 20 percent at a marginal heat saving cost of Y 0.085/kWh.

(c) Increasing the insulation in roofs (from 100 mm to 200 mm aerated concrete) would reduce heat transfers from the roof by 40 percent, at a heat saving cost of Y 0.048/kWh.

(d) Overall, combining window improvements with better insulation of walls and roofs could reduce heat losses in such a building by 50 percent at a 6 percent increase in the capital cost of a building.

These results are probably valid for other cities with central heating of mid rise apartment buildings.

15. Retrofitting. Other research indicates that there is scope for economic retrofitting of existing buildings; one international experiment suggests that heat losses could be reduced by 30-40 percent by taking the following measures: (i) better weather stripping; (ii) installation of additional glass panes on the inside of steel windows; and (iii) installation of rockwool (e.g., 50 mm) and gypsum board.

12/ Current designs of residential buildings in Beijing require 120-130 kWh of heat per year, according to the calculations made in the study. Net heat consumption was calculated by the following method: gross heat supply of 206 kWh/m^2 x 0.55 (combustion efficiency) x 0.85 (distribution efficiency) = 120 kWh/m^2 net heat supply. A room air temperature of 16°C and a ventilation rate of 1.4 ach were assumed, both of which are conservative.

13/ Using a discount rate of 10 percent and 20-year project life.

16. Transition Zone. In the transition zone, where there is no central heating, it appears that reducing infiltration through windows by double glazing and better insulation would be economic also, based on a recent demonstration project in Wuxi. In addition, a modeling study in the early 1980s estimated cated potential heat loss reductions of 40 percent by better insulation of windows in the Shanghai area.14/ Since the indoor temperature can end up being not more than 6°C in the transition zone at some points during the winter, by improving windows it may be possible to increase the temperature to 9-10°C during such periods.

Analysis of Economic Savings from Insulation Investments

17. At Attachment 2 is a summary analysis of annual savings for various insulation investments, using an economic cost for central heating of Y 100/Gcal, consistent with the central heating costs cited in Annex 6. The summary highlights the large return (36 percent) and short payback period (less than three years) for investments in improved windows in new buildings. Returns on wall and roof insulation are satisfactory, although payback periods (about eight years) are much longer than those of window investments. Combining investments in window improvements and wall and roof insulation offers an estimated return of 28 percent and a payback period of less than four years. Obviously, further refinement of these analyses is needed, but these preliminary results indicate the beneficial potential of insulation investments.

Long-Run Impact of Insulation

18. One has to be careful, though, about citing energy and coal savings. Because of the low temperatures in houses at the present time and a situation of constrained demand, even with energy conservation people are likely to demand more comfort and thus more heat in the future as incomes rise. In other words, insulation may help raise the base temperature level, but in the short term the same amount of or even more fuel will be used. Insulation protects against the opportunity costs of rising future demand over the medium to long term.

Recommendations for Government Policy

19. Motivating energy-saving measures in residential buildings has been difficult in most countries because of concern over housing costs, contractor distrust of new practices, and the inability of consumers (the buyers) to evaluate clearly the long-run savings from building conservation measures, particularly if they add to the initial cost of housing. Instituting a metering and charge system based on heat consumption and insisting on cost recovery should help, over time, to raise the attention of building owners to operating costs of building investment decisions.

20. International experience has shown that because of the complexity and timing of benefits accruing from building conservation measures, market forces are not totally effective in promoting investments in housing insulation.

14/ Huang et al., p. 979.

Virtually all countries have had to institute mandatory building regulations to introduce cost effective conservation measures into the housing stock. Incentive programs and subsidies, as well as information, technical assistance and training programs, are also common tools to encourage insulation, particularly for improvements to existing housing.

21. In view of other country experience, Chinese authorities should give urgent consideration to developing a strategy with the following elements:

- mandatory standards for new housing with central or district heating should be phased in promptly;

- development of the manufacturing infrastructure and capability to produce meters, control valves, and insulation materials;

- development of an investment program to install meters on old and new housing and modern radiator systems in new housing;

- institution of a heat charge system based on consumption, over time achieving full cost recovery, taking into consideration the economic costs of resources such as coal and electric power;

- financial support for continued research on new designs for buildings, for investigation of the potential for wood window frames, and product development, testing and manufacturing;

- promotion and support of education and financial incentives for conservation investments, including retrofit of older buildings.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Assumed Building Specifications for Some Cities

City	Outer walls	Roof	Windows	Ventilation rate (ach/hr)
Harbin	480 brick (k=0.8) 20 plastering	Waterproof layer 20 cement mortar 200 aerated concrete 70 slag mortar 130 hollow concrete 20 plastering	Double glazed wooden windows	0.8
Beijing	370 brick (k=0.8) 20 plastering	Waterproof layer 20 cement mortar 100 aerated concrete 70 slag mortar 130 hollow concrete 20 plastering	Single glazed steel windows	1.4
Xining	= Beijing	= Beijing	= Beijing	1.4
Jinan	= Beijing	= Beijing	= Beijing	1.4

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Economic Analysis of Insulation Investments in New Buildings

Heat Cost (Y/Gcal): 100.0 /a

	Savings	Investment		Per apartment				As %	IRR/b	Payback
	Mcal/m²	Y/m²	Y/Gcal	Area (m²)	Savings (Mcal)	Cost (Y)	Savings (Y/yr)	of heating bill (%)	(%)	period (years)
Improved windows	321.6	90.0	280	7.5	2,412	675	241	27.4	36	2.8
Improved walls	11.2	9.0	804	20.0	224	180	22	2.5	11	8.0
Roof insulation	9.0	8.0	886	20.0	181	160	18	2.1	9	8.9
Combined investments			360		2,817	1,015	282	32.0	28	3.6

/a Comprised of a coal price of Y 20/Gcal and fixed costs of Y 80/Gcal.

/b Based on a 20-year life of investment.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Role of Gas: Petroleum and Coal-Based 1/

A. Introduction

1. Fuel diversification is an option that China in large part does not enjoy. Opportunities to use natural gas or other forms of gas could improve energy efficiency in a variety of applications and reduce the environmental impact of energy use. While gas resources are limited, not all sources are being fully developed or exploited. Moreover, in the longer term, if more natural gas supplies are not available, modern coal gasification offers promise as a source of gas for industrial and household use.

2. This annex first reviews existing and potential sources of gas, as outlined in Table 1. They include:

(a) petroleum-based gas (natural gas, LPG);

(b) coal gas from municipal coke ovens, vertical retorts, and small gasifiers;

(c) by-product or process gas potentially available at integrated steel mills (from in-plant coke ovens) and oil refineries; and

(d) coalbed methane released from coal seams.

The second half of this annex examines more closely the role of gas in the residential sector because of municipal government aspirations to increase the supply of gas in households. It discusses the results of an economic analysis of coal gasification options being considered at the municipal level.

3. Some important points stand out from this review. First, gas is priced so low in many applications in China that there is often no incentive for potential suppliers to develop or produce gas resources. Yet, in view of the economies and better environmental impact of gas use, a terrible cost is incurred when investments to use available gas resources are delayed.

4. Second, in view of the shortage of natural gas and the large capital commitments involved in coal gasification, it makes sense to investigate more systematically the value of these sources of gas for different uses in the economy, considering both energy efficiency and environmental impact. This should help determine the priorities for use of both natural gas and various forms of coal gas. Understanding more explicitly the potential value of gas

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1/ This annex is based on analyses by D. Simbeck. It benefited from discussions with staff of the North China Town Gas Design Institute and data provided in Working Paper No. 6, Environmental Strategy Research Center, NEPA.

to the economy might also create the necessary support among policymakers to develop available resources more rapidly and to adjust gas prices.

Table 1: SOURCES OF GAS AND THEIR POTENTIAL

Sources of gas	Present Use	Potential
Petroleum-Based Gas		
Natural gas	Chemical and fertilizer industry primarily, some town gas	Full potential unknown. Supplies presently limited by known reserves and lack of resources to exploit available reserves
LPG	Household cooking primarily	Supplies limited by refinery capacity
Heavy oil gasification	Household gas in a few cities	Limited, as it is more expensive than coal gas
Coal Gas		
Small fixed bed gas producers (using steam coal)	Low calorific value gas for utilities	Could be used to a greater extent to substitute for rich gas in plants, releasing the latter for town gas
Cyclic gas producer (using anthracite)	Low grade ammonia production	Common for small-scale ammonia production
Municipal coke ovens	High value by-product gas used in industry and households	Good source of gas where supplies of good coking coal are available
Vertical retort gas	Household cooking	Good potential at small scale
Modern coal gasification	No investments to date	Medium to long term potential for industry and households
Small two stage gasifiers (similar to cyclic gas producers)	A few are being put into operation to supply gas for cooking	Prospects uncertain because of operating problems
Plant Gases - Coal- and Petroleum-Based		
Medium calorific value gas from coke ovens in integrated steel plants (same as coke oven gas mentioned above)	Normally used inside plant	Large supply available, some of which could be used as town gas if producer gas substitutes for in-plant use
Medium calorific value gas produced in oil refineries	Used inside plant	Same as above
Coalbed Methane		
Gas from coal seams	In mining communities, for cooking primarily	Full potential unevaluated

B. Background on Petroleum-Based Gas Supplies

Natural Gas

5. Natural gas is in short supply in China; it represents only 2 percent of commercial energy consumption. Low producer prices impede exploration and development of natural gas; state petroleum companies have no incentive to develop gas resources at a loss, particularly when their major product--oil--brings a much higher price, including badly needed foreign exchange.

6. In 1989, 14.4 billion m^3 of natural gas were produced, of which about 9 billion m^3 were sold commercially; the rest was used in oilfields or flared.2/ Most of the gas sold goes to industry, primarily for fertilizer and petrochemical production. Ammonia production is a high value use for the gas because of the high energy efficiency achieved; it represents half the energy required in traditional ammonia production using coke or anthracite.

LPG

7. Most of annual LPG production (about 1.24 million tons in 1987) is used for urban household cooking in major cities, such as Beijing, close to oil refineries. Relatively low cost to produce, LPG supplies are limited by refinery capacity in the country.

Heavy Oil Gasification

8. Heavy oil gasification is utilized in China to produce a small amount of manufactured town gas in select cities, for example Beijing and Shanghai. The high value of oil relative to coal detracts from its use, and officially oil gasification is only used to meet peak winter demand for town gas. It appears, though, that oil gasification may be used for more than just winter peaking.

C. Coal-Based Gas and Coal Gasification

Background

9. The gasification of coal has a history going back at least 60 years. The early gasification processes involved either coke oven gas or an ammonia synthesis gas. In the 1930s, the Lurgi high pressure coal gasification process was developed, and since then it has had long commercial experience. In the United States, prospects of a natural gas shortage in the future and environmental regulations have spurred further technological development of coal gasification. Several modern oxygen blown coal gasification technologies are now available.

Present Sources of Coal Gas in China

10. China has long experience with coal gasification from coke ovens, vertical retorts, and small fixed bed or cyclic gas producers. The latter two technologies produce low calorific value gas. Small fixed bed gas producers gasify steam coal to produce a gas used in plant utilities. Cyclic water gas

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2/ Reports by MOE indicate that a significant share of associated gas is still flared.

reactors gasify coke or anthracite to produce ammonia. Coke ovens and vertical retorts produce high to medium value gas which can be used in industry and households. Two stage gasifiers (similar in technology to cyclic water gas reactors, but using sized steam coal) represent an older European technology recently introduced in China as a source of town gas; only a few two stage gasifiers have been commissioned. Coke ovens, vertical retorts and two stage gasifiers are described in more detail below, because of their potential as a source of town gas.

11. Coke Oven Gas. In producing coke for steel making, modern slot-type coke ovens also produce a methane and hydrogen rich fuel gas from pyrolysis of the coke. The gas yield from coke ovens is about 320 m^3 of gas (4,200 kcal/m^3) per metric ton of metallurgical coal. Only about 22 percent of the energy of the feed coal is converted to coal gas. The fuel required to heat the coke oven is about one-half of this gross gas yield; thus, some gas is available for town use. In addition, those coke ovens with dual fuel design in China can utilize low heating value gas to heat the coke oven, thereby making all the higher value coke oven gas available for town gas.3/ Coke ovens in China operate either as stand alone, "merchant" plants or part of large integrated steel mills. Most coal gas supplies come from merchant coke ovens closely affiliated with municipal governments. The principal constraint on expansion of coke oven by-product gas is the future availability of prime metallurgical coal.

12. Vertical Retorts. Vertical retorts are much like coke ovens except they are used in a continuous process and are more economical in smaller sizes. They too involve an indirectly heated pyrolysis of coal. The key difference is that the coke produced in the vertical retort is much poorer quality relative to that used in a blast furnace or foundry. Therefore, the coke from a vertical retort is usually gasified to produce more coal gas.4/

13. Small Two Stage Gasifiers. Some smaller cities are planning investments in two stage gasifiers (which are modifications of two stage gas producers). This technology was originally developed about 40 years ago, although it was never used extensively because of competition from other technologies.5/

3/ To do so, merchant coke ovens have to invest in gas producers to generate the low value gas. Steel mills can substitute blast furnace (if that is being used elsewhere in the plant, then they too would have to invest in gas producers).

4/ This is done with gas producers to produce the fuel gas required to heat the retort and a cyclic water gas reactor for additional town gas. However, the coal gas produced in the water gas reactor is only 2,500 kcal/m^3 and is over 20 percent CO. Therefore, LPG is sometimes added to the blended water gas and retort gas to improve the heating value.

5/ The process is one in which lump steam coal is fed to a moving bed gasifier operated at atmospheric pressure, producing a gas which has a heating value of only 2,500-3,000 kcal/m^3 and contains 25-30 percent carbon monoxide.

14. The development of the cyclic two stage gasification technology in China needs careful scrutiny. The key advantages of this technology are the potential for smaller sites, the low capital investment, and the avoidance of imported technology and equipment. However, this technology is likely to have many operating and environmental problems, due to cyclic operation at atmospheric pressure.6/ The throughput capacity per unit gasifier is low, and the heating value (2,500-3,000 kcal/m^3) is 25 percent below the national standard for town gas. In addition, it does not meet standards for carbon monoxide of less than 10 percent. The lower calorific value could affect stove operation, and the higher level of carbon monoxide (25-30 percent) could be dangerous, although there are ways to reduce risks, such as scenting the gas. A potential modification of this process would be to use some of the gas for ammonia production, preserving the part of the gas that is high value for town gas (discussed at Attachment 2). Research should go into such an adaptation.

Potential for Modern Coal Gasification

15. Since China has insufficient reserves of natural gas and the prospect of coke oven gas production is limited, the country may have to invest in processes for complete gasification of coal in the long term. Modern coal gasification processes gasify steam coal under high pressure and temperature, together with partial or full methanation to improve heating value. They hold promise in China because of ample supplies of low sulfur coal. Investments in several processes are being considered, but major investments have not yet been made.

16. There is a general perception in China that oxygen blown gasification is more expensive than air blown operations due to the oxygen plant requirement. This is not necessarily true. Assuming reasonable plant size to achieve economies of scale, the unit cost of the gas may be lower, because of the high volume of gas produced (at 4,000 kcal/m^3). Since gas distribution investments remain the same, irrespective of the quality of gas, the heating value of the gas should be as high as possible to optimize the distribution network. In addition, modern coal gasification offers savings in operating costs and the costs of environmental control compared with alternative atmospheric, batch-type gasification. But the initial investment costs in modern coal gasification are very large, and they require imported technology, principally the oxygen plant.

17. The potential applications for oxygen-blown coal gasification are:

(a) various industrial processes (for example, hydrogen, methanol, ammonia and sulfur production);

(b) supply of town gas; and

(c) coal gas/combined cycle (CGCC) power generation.

6/ In November 1988, the city of Fuxin in Liaoning province installed a two stage gasifier based on Polish design, but it is having operating difficulties.

18. Different processes have advantages in different applications. "Entrained flow" gasification (or "slurry-fed entrained flow" gasification), which uses high rank coals or coals with high fines content, is good for ammonia, methanol and sulfur production. While coal gasification for ammonia production is less energy efficient than using natural gas as the feedstock, it is more efficient than typical small-scale ammonia production by gasifying anthracite via cyclic gas producers, which is common now (refer to Annex 9 on ammonia production). In areas where high sulfur coal is used, it may be economic to invest in coal gasification for joint ammonia and sulfur production. Methanol production has large potential as a transportation fuel or as a cooking fuel for rural areas. Another advantage of methanol is that it avoids the cost of converting all of the synthesis gas to hydrogen as occurs in ammonia production.

19. The well-commercialized, modern "moving bed" gasification process is a good choice for town gas application, because of its lower oxygen requirements and higher methane and hydrogen content.7/ In fact, the original development and use of this technology was for town gas supply in Europe in the 1930s-1950s. Coal gas from a moving bed gasifier has a heating value of about 4,000 kcal/m^3, if the carbon dioxide is removed in the gas clean-up to remove sulfur. The process normally uses sized coal and generally favors the use of low rank coal; fines can be a problem. Nevertheless, the moving bed gasifier can use coals with high fines content, if it is built near a pulverized coal-fired power plant which could use the fines. It also produces tars and liquids which could be used in China.

20. Coal gasification/combined cycle power generation (CGCC) is considered potentially attractive in the United States because of prospective shortages of natural gas in the next 10-15 years and increasingly stringent environmental regulations. Also, co-production of syngas and chemicals is contemplated; this is feasible in the United States because base load power generation is low enough to make it feasible (base load power requirements are much higher in China). Large capital investments in CGCC over the long term in China will depend on several factors: (a) the strictness of environmental standards; (b) the alternative options for meeting those regulations; and (c) very importantly, the trade-offs in using gas for electric power versus other applications. From an environmental standpoint, coal gasification may be better utilized in sectors where options for environmental control are more limited, in the household sector for instance.

D. Gas From Industrial Plants

21. A potentially large source of gas, largely ignored at the present time because of institutional constraints and lack of incentives, is the medium calorific value gases generated in integrated steel plants (in their coke ovens, for example) and refineries. Those gases could be harnessed at relatively low cost for town gas use.

7/ Other processes require twice as much oxygen for coal gas. Several proposed coal gasification plants for town gas are based on co-production of methanol. It is likely that this is done in order to improve revenues in order to subsidize town gas prices and in order to export products to generate the foreign exchange.

22. Steel Plants. An example are gas supplies generated at captive coke ovens in steel plants. Presently, much of this gas is used as process gas within the plant, a lower value use. Diverting the gas for town use would require some investment, but it would be much less than investing in new coke ovens or coal gasification plants. One approach is to recover the low value CO rich gas from the basic oxygen furnace and use it in the coke oven, thus freeing the higher value gas. If the furnace gas is already being used, gas could be generated by three other methods:

(a) use fluidized bed combustion of steam coal or coke "breeze" to preheat blast furnace air; this would free blast furnace gas for the coke oven;

(b) produce low energy content fuel gas via gas producers to free coke oven gas; and

(c) produce medium energy content fuel gas via cyclic water gas reactors to free coke oven gas.

The estimated potential supply of coke oven gas produced at steel mills is over 67 x 10^{12} kcal/year, sufficient on its own to meet much more than present coal gas targets for the year 2000 (refer to Table 1). Of course, not all of this gas would be available, because of constraints of location and type of coke oven (to burn low energy gas, the oven must be a duel fuel design). Still, the potential supply is large.

23. Refinery Gas. Another prospective source of gas that apparently has not been tapped is oil refinery process gas. By using more coal for steam generation and process heating, via direct combustion or from coal-derived gas, the richer refinery-produced gases could be directed to residential use. The gas derived from the refining process is of high calorific value (4,500 kcal); it represents a potentially large, low cost source of gas, estimated at 18-27 billion m^3 per annum, or 80-120 x 10^{12} (8-12 percent of the crude feed). Use of coal in oil refineries could include the following:

(a) steam generation;

(b) process heating via coal gas or direct coal combustion;

(c) coal derived fuel gas via gas producers; and

(d) coal derived synthesis gas via cyclic water gas reactors.

These coal-based processes have the potential for replacing essentially all the refinery gases, which could then be used as a large source of town gas. It is more economical to use coal directly and indirectly (via coal gasification) in oil refineries than to build specific coal-based town gas manufacturing plants.

24. Both sources of gas described above are potentially very large. The cost of investments to use this gas (about Y 100-150/Gcal) would be less than a program of building both new coke ovens and stand-alone gasification plants

(averaging about Y 300-350/Gcal). Therefore, these sources warrant investigation in individual cities to determine how much could be practically supplied. Strategies should then be developed (including price and tax incentives) to encourage enterprises to make the incremental investments necessary to supply the gas to municipal gas companies.

E. Utilization of Coalbed Methane

25. Coal mining is also a source of gas; it is either drained or naturally released into the atmosphere in the process of mining.8/ Many deep underground mines already require some form of gas ventilation. The explosiveness of methane in coal seams historically has posed a hazard to underground mining. The most common solution is to install ventilation systems in the mines, but most such systems do not allow the gas to be used. Various techniques are now used in a number of countries to drain the gas before or during mining and then to utilize it: in boilers for steam raising, space heating and hot water supplies; for some electricity generation; in brickworks; or, if the methane content is high enough, as pipeline quality gas.9/

26. The economics of using the gas depend on the following: the continuity and quality of supply, the proximity of users and, relatedly, the costs of collecting and distributing the gas. Evaluating the economics is very site specific. Factors affecting the volume of supply are: the depth and permeability of the coal seam; lost coal faces and delayed face transfers when extraction occurs during mining; old workings above and below the working face; and loss of purity. Methane purity varies and is affected by the following: strata conditions; the proximity of the gas source to workings; ventilation pressures; and borehole geometry and spacing. In some countries, the gas from the mines is enriched by blending it with other sources of gas.

27. In China, coal mine gas is presently a small source of gas for cooking and heating in mining communities; only an estimated 250-300 million m^3 per annum is utilized.10/ But its potential may be much greater, given the depth and relatively high gas content of coal reserves in the country. Resources are needed to evaluate the full economic potential of draining gas

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8/ Methane is a potent greenhouse gas, estimated to be 20 times stronger than carbon dioxide on a weight basis over a 100 year period. In addition, methane emissions increase levels of troposheric ozone and may contribute to stratospheric ozone depletion.

9/ Coalbed methane extraction occurs in a few states in the United States (the largest exploitation being at a gassy mining area in Alabama). Because of the relationship of methane emissions to the problems of global warming and in view of decreasing supplies of domestic petroleum and natural gas, greater attention is now directed at the full potential for coalbed methane gas extraction in the United States. Other countries utilizing some coalbed methane are Australia, Poland, Germany and the UK.

10/ Some mining companies in China also supply gas to their communities by gasifying a small amount of the coal produced (via simple gas producers).

from mine seams to supply gas to mining communities and possibly nearby cities. Because one of the extraction techniques involves drilling drainage boreholes 5-10 years prior to mine development, extensive coal seam gas evaluations should be undertaken as soon as possible in major mining areas.11/

F. Role of Gas in the Residential Sector

Beneficial Impact of Gas

28. Whether petroleum or coal based, gas is a more convenient and environmentally superior fuel compared to direct combustion of solid fuels in households. Direct coal combustion produces particulates, carbon monoxide, and polycyclic aromatic hydrocarbons (PaH); almost all the sulfur in the coal is converted to SO_2. All these pollutants are discharged near ground level. In addition, the ash left over from combustion must be collected and disposed of. Town gas does not produce these pollutants when combusted in the home. Therefore, an increased gas supply to cities in China could have a significant beneficial effect on the environment.

29. Natural gas and LPG are the favored fuels for town gas because such gases are higher in heating value, have a lower explosive range and are less toxic. Their development also usually requires less investment (in the case of natural gas, this of course assumes sufficient confirmed reserves). Coal gas has the disadvantages of higher carbon monoxide (CO) and hydrogen content which reduce heating value and increase toxicity and explosive range. But, as long as standards for the gas are met, coal gas is a better fuel than direct coal use.

30. Probably the most serious environmental concern related to coal-based gas technologies is waste water, because the raw waste contains phenols. This can be controlled by biological treating, but it requires resources and a commitment to undertake the necessary investments. A discussion of environmental aspects of coal gasification is at Attachment 1.

Present Coverage of Urban Areas

31. While data are difficult to confirm, approximately 38 million people in urban China in 1987 were supplied with gas (about 3 percent of the total population and 13 percent of the urban population).12/ The total supply of gas for domestic use comes from the following sources, based on calorific value: natural gas (32 percent), LPG (36 percent), coke oven gas (22 percent), oil-derived gas (9 percent) and miscellaneous (1 percent). In volume terms, coal gas is the largest source.

11/ In planning predrainage, however, careful design is necessary, in order not to interfere with future coal production or mine safety.

12/ Of the gas supplied to urban areas (through municipal gas companies), about 53 percent of the gas goes to industry and public or commercial establishments.

The Disincentive of Gas Prices

32. Unit prices of gas for use in households and local industry in major cities are generally in the following range: 13/

Natural Gas 14/	20-22 fen/m^3	@9,000 kcal/m^3
LPG	29-36 fen/kg	@11,700 kcal/kg
Manufactured Gas	8-15 fen/m^3	@3,500-4,500 kcal/m^3 15/

Translating these prices to calorific value terms, they equate to about Y 20-25/Gcal, which does not cover the cost of producing and distributing the gas. As an example, the price of gas is compared to the average incremental cost (AIC) of coke oven gas (the cheapest form of coal gas) which was estimated in this study.16/ Ex-plant gate, the AIC is Y 34/Gcal (before distribution costs), 70 percent higher than the present price of town gas. Other sources of coal gas will cost even more--in the range of Y 75-150/Gcal (AIC basis). Thus, existing municipal gas prices are extremely low relative to the costs of gas, making investments to supply gas a terrible drain on municipal finances, if gas is subsidized to the extent indicated here. Moreover, producer prices of gas (for natural gas and LPG, for example) are kept artificially low, creating a disincentive to supply gas to cities.

33. Because of the convenience of gas, it is likely that residential consumers would pay a much higher price for town gas than they currently pay, and indeed Chinese municipal authorities are strong advocates of higher gas prices.17/ They are starved of funds to make investments in greater gas supplies or to pay prices which will attract available gas (from the petroleum industry and steel plants) to the residential sector. It seems clear that consumer gas prices will have to rise to make investments in substantially larger gas supplies affordable.

Targets for Household Gas Supplies in the Future

34. The government plans to increase domestic coverage of town gas for cooking from about 40 million people in 1987 to 120 million people in 2000 (or

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13/ These are municipal gas prices and do not reflect the price of gas for ammonia and chemical production, which may be higher.

14/ Even lower natural gas prices are charged in parts of Sichuan province --13 fen/m^3.

15/ The upper range cited here is the gas to local industry charged by city gas companies. Because gas sales to industry are often be at higher prices, there is a greater incentive to sell to industry. In fact, municipal coke ovens often sell about half of their gas to local industries.

16/ See results at Table 3 and Attachment 3.

17/ In order to help pay for the distribution investments needed to supply gas, municipalities already charge potential consumers, via their employers, up-front fees or sell bonds to them.

an estimated 40-50 percent of large and medium size cities). Table 2 shows the composition of town gas supplies in 1987 and projected for 2000.18/ The projections are consistent with Chinese projections for total people supplied with gas and assumed annual town gas consumption per person. The actual coverage will depend on urban population growth.

35. The table highlights the extent of expansion planned for both natural gas and coal--three to fourfold increases in volumes supplied. LPG production would increase by about 50 percent, but it is dependent on refinery expansion. Meeting these ambitious targets will depend on making major investments in the supply of natural gas and coal gasification. Other than the targets, though, there appears to be no national strategy to maximize the availability of gas from all sources and no explicit recognition of the funds required to do so.

Table 2: TOWN GAS CONSUMPTION PROJECTIONS

	1987	2000
People supplied with gas	40 million	120 million
Population of major cities	110 million	250 million
Percent supplied with gas	36%	48%
Gas consumed per person per year	0.8 Gcal	0.85 Gcal
Total urban gas supply	32.2x10E12 kcal	100x10E12 kcal

	1987			2000			
Sources	Volume	10E12 kcal	% share	Volume	10E12 kcal	% share	% increase
Natural gas	1.16 billion m^3	10.4	32	5.7 billion m^3	51.5	52	395
LPG	1.0 million tons	11.6	36	1.2 million tons	17.0	17	47
Coal gas	2.0 billion m^3	7.0	22	8.0 billion m^3	28.0	28	300
Oil gas	0.8 billion m^3	2.8	9	0.9 billion m^3	3.1	3	12
Misc. /a	NA	0.4	1	NA	0.4	-	-
	Total	32.2			100.0		211

/a Including coal seam gas.

36. While favored cities or those close to gas fields will receive natural gas, many municipal governments are considering various coal gas projects as the answer to the gas supply. Planned sources of coal gas are: municipal merchant coke ovens, steel plants, two stage gasifiers and, in some cases, modern oxygen-blown coal gasification.

37. Since demand for coke is strong, many municipalities intend to increase gas production along with expansion of coke production. In fact, the higher heating value and lower CO content of coke oven gas should favor its

18/ The various data sources were inconsistent; therefore, many key assumptions had to be made. The table is generally consistent with projections by the Ministry of Urban Construction and the North China Municipal Engineering Design Institute. They key difference is that most town gas projections in China do not include gas from heavy oil gasification.

use for town gas over other coal-based sources. But this gas is only a by-product of coke production, and therefore future supplies will be dependant on steel industry demand and availability of metallurgical coke (high quality low volatile metallurgical coals are in short supply in China).

38. However, many municipalities are failing to consider potentially large volumes of gas which could be made available through incremental investments to harness additional rich gas generated at steel plants and oil refineries--at roughly half the cost of large-scale investments in coal gasification. But town gas prices must be increased to provide the supplying industries with the economic incentive to make those investments.

The Economics of Coal Gasification for Town Gas

39. Because of the strong interest in coal gasification in China, the economic costs of the four principal technologies being considered for coal-based town gas were analyzed in this study. The technologies are:

(a) coke ovens;

(b) vertical retorts;

(c) small-scale two-stage gasification; and

(d) pressurized, oxygen-blown gasification.

40. Table 3 summarizes the assumptions and results of economic analyses for the four different coal based town gas manufacturing options. Average incremental costs were estimated for each, on both a volume and calorific basis. Detailed NPV analyses are presented at Attachment 3.

41. The analysis assumes that stand alone coke plants use coal gas produced in gas producers to supply the low heating value gas to heat the coke oven, thus freeing the maximum amount of high value gas for town gas use. The prototype used for the analysis of a modern coal gasification plant is a modern Lurgi fixed bed gasifier, because it offers cost advantages in producing town gas. The coke oven and Lurgi gasification installations are relatively large plants; the latter is not feasible at smaller scale. The vertical retort and two stage gasifier are small plants.19/

42. The results at Table 3 show that town gas produced from coke ovens is clearly the most economical of the four technologies analyzed, because of the relatively low incremental costs to harness that gas at a plant which is producing a high value product, coke. Vertical retorts also produce a large amount of coke; retort coke, however, generally has a much lower market value and size than coke from coke ovens. The other technologies do not offer a large by-product. The comparison between a modern Lurgi and a two stage gasifier is noteworthy, indicating that on a calorific value basis the modern gasifier is less expensive, due to economies of scale. Therefore, in areas where a large population could be served, modern coal gasification is potentially economic.

19/ Coke ovens could be as small as the vertical retort plant size; however, the gas cost would be higher than that of large coke oven plants.

Table 8: TOWN GAS ECONOMICS
(Ex-Plant Gate Costs, Excluding Distribution Costs)

Process	Coke oven /a	Vertical retort	Pressurized oxygen-blown gasifier	Two-stage gasifier
Feed Stock	Coke /a	Retort coal	Steam coal	Sized steam coal
Yuan/ton /b	--	200	150	175
Tons/yr	--	92,500	660,000	73,656
Utility Coal	Steam coal	Steam coal	Steam coal fines	
Tons/yr /c	396,000	40,765	220,000	(Steam co-produced)
Plant Fuel Gas	Gas producers with steam coal	Gas producers with retort coal	None required	None required
By-products (Order of importance)	Tars/oils /d Sulfur	Retort coke Sulfur	Tars/oils Sulfur	Tars/oils
Capacity				
m^3/d (330 days)	1,200,000	250,000	2,000,000	240,000
$kcal/m^3$	4,200	4,200	4,000	3,000
10E12 kcal per annum	1.66	0.346	2.64	0.238
Capital Cost				
Yuan (million)	130	190	1,000	95
Average Incremental Cost (AIC)				
1. Volume basis ($Yuan/m^3$)	0.14	0.47	0.45	0.44
2. Energy basis (Yuan/10E6 kcal)	34.2	111	113	148

/a This represents incremental investments at the coke oven. Coke feed is about 850,000 tpa.
/b Estimated economic prices are used, not existing prices.
/c Tons per annum at 5 Gcal/ton.
/d The main product of the coke oven process is coke, of course.

Gas for Heating

42. Coal gas might also be considered for heating as well as cooking, particularly to achieve economies of scale in coal gasification. Moreover, distribution systems are optimized by supplying gas for both cooking and heating. Many municipal governments are considering two distribution networks--one for gas for cooking and another for district heating. The size of these investments are massive; it is too financially burdensome and probably not economically optimal to invest in two capital-intensive networks. Therefore, where gas distribution networks already exist, or modern coal gasification is contemplated, supply of additional gas for heating should at least be considered, before plans are made to go ahead with district heating networks as well. During summer, modern coal gasification plants could co-produce methanol, for use in rural cooking stoves, for example.

Distribution Costs

43. The costs cited above are ex-plant gate. Comparable data on capital and operating costs are lacking in regard to distribution. Estimates based on international experience indicate that capital costs might be in the order of Y 500/kW ($107/kW) including building pipes. Further investigation of the economic costs is needed.

45. Typical distribution charges for town gas in China are only Y 0.03-0.04 per m^3 or Y 7-10 per Gcal; they are supposed to cover operating costs. Capital costs appear to be covered by a combination of up-front hook-up fees paid by the consumer (usually the employer of the consumer) and direct government subsidies. A hook-up fee is charged, often cited as Y 1,000-1,500 per household, equivalent to about Y 250-375 per Gcal/year of capacity.20/ Assuming a 15 percent capital charge, this equates to a capital-related annual charge in the range of Y 38-56/Gcal. Therefore, based on the financial costs cited above,21/ operating and capital-related costs of town gas distribution (excluding production costs) would be about Y 45-65 per Gcal.

46. It is worth noting that gas distribution costs should be significantly lower than those of district heating. This is because gas requires no insulation or condensate return. In addition, the energy density of town gas is significantly higher. As mentioned earlier, in order to make optimum use of an investment in a distribution network, the heating value of the gas should be as high as possible.

Comparative Capital Costs

47. The investments to increase supplies of coal gas from new coke oven and modern coal gasification plants--by $21x10^{12}$ by the year 2000--will be significant. Assuming 50 percent of the gas comes from new coke ovens and 50 percent from large-scale gasification, unit investment costs (excluding distribution costs) are estimated to be Y 300-350/Gcal, or Y 10 billion over the period (including contingencies).

48. In contrast, gas supplies potentially available in integrated steel mills and oil refineries far exceed the target increases in gas planned over the next ten years. And the unit cost of making some of those supplies available is about one-half--an estimated Y 100-150/Gcal. This indicates the clear advantage of trying to harness this gas wherever possible.

Recommendations for Supply of Town Gas

49. In the short to medium term, various cities will rely on municipal coke ovens (and their expansion) to supply gas as a byproduct. The principal danger is overexpansion of such coke ovens and problems in securing metallurgical coal. Efforts should also be made to harness the ample supplies of reasonably low cost, methane-rich gas available in existing steel mills and oil refineries in China, which could be more effectively utilized as residential town gas. Town gas prices must be increased, however, to provide those industries with the economic incentive to make investments to free up the higher value gas. Higher town gas prices are not likely to reduce residential demand for gas. This is because of the better quality and convenience of gas cooking relative to solid fuels. Furthermore, increased town gas utilization in Chinese cities has a significant potential for reducing pollution.

20/ Assuming 4 people per household and 1 Gcal/person/year.

21/ Which may be subsidized and, in any case, may not reflect full economic costs.

50. High government priority should also be placed on finding and using natural gas, as this clean, high value fuel ought to play a bigger role in town gas supply. To encourage both further exploration for and development of natural gas, again the price of gas should be raised.

51. If, over the next ten years, there is not a significant increase in exploitable reserves of natural gas, China should then consider adopting one of the modern gasification processes, under high pressure and temperature, together with partial or full methanation to improve heating value. The country has abundant reserves of fat and gas coal as a suitable raw material. Until town gas prices become remunerative, though, it will be impossible to afford such investments.

52. Coal gasification plants based on modern oxygen-blown, continuous, pressurized processes are likely to be a better technology than two-stage gasifiers. The well commercialized moving bed gasification process (not antiquated Eastern European designs) is a good choice for this application. In addition, it is best to consider construction of such plants next to large power plants (to avoid fines problems), use of low rank coals, and investments in low cost gas/liquid clean-up alternatives.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Emissions From Coal Gasifiers

Point of Consumption

1. At the point of gas use, emissions are significantly reduced. There should be no emissions of particulates and SO_2 emissions are substantially reduced--0.4-3.3 kg/ton coal depending on the original sulfur content of the coal. CO content would depend on the type of gas (gas from two stage gasifiers will have higher CO content). In any case the gas should be scented. A clear advantage of coal gasification is that it minimizes emissions near consumers in urban areas and reduces ambient concentrations in such areas. Potential emissions are concentrated at production sites, where they can be better controlled.

Point of Production

2. Type of Gasification Process. Most modern coal gasification technologies operate continuously at pressure, which assures significantly less environmental problems than batch processes, like that of coke ovens. Coke ovens and two stage gasifiers have the highest air emissions due to their cyclic operation at atmospheric pressure.

3. Particulates. Most of the dust in the product gas would be removed at the gas quenching stage. With coke ovens there are potentially more emissions, when pushing the coke out of the oven after carbonization and also from the quenching operation. These are difficult to quantify and are dependent on local conditions and practices.

4. SO_2 Emissions. In gasification, most of the sulfur in the coal is converted to H_2S. It is possible to remove virtually all of this sulfur, if required. A realistic target in China may be 90 percent removal. For example, in the case of a modern Lurgi plant, about 10 percent of the S would be emitted. S emissions as SO_2 would range from 0.8 kg SO_2/ton coal to 6.5 kg SO_2/ton coal, about 50 percent of which would be released at point of use (see above). For coke oven plants, up to two-thirds of the sulfur would be retained in the coke, leading to much lower sulfur in the gas.

5. Water Pollution. Probably the most serious environmental concern related to coal-based town gas technologies is waste water, because the raw waste contains phenols. This can be controlled by biological treating, but requires resources and a commitment to undertake the necessary investments.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Some Recommendations Concerning Adaptation of Two-stage Gasifiers for Town Gas

1. Two stage gasification is based on modification of conventional cyclic water gas reactors, using sized steam coal instead of coke or anthracite. The process is operated with three cycles, whereas a conventional water gas reactor has only two cycles. The first cycle is upward blowing with air to produce red hot char. The hot off-take gas contains some fuel gas value and is combusted to generate all of the steam requirements. Second, steam is blown upward through the bed, producing a pyrolysis gas removed from the top of the bed. This gas is rich in methane but contains tars and oils. Third, steam is blown downward from a midpoint of the bed which is mostly hydrogen and carbon monoxide.

2. The two gas streams are purified and blended into a town gas which has a heating value of 2,500-3,000 kcal/m^3 and is 25-30 percent carbon monoxide. This gas does not meet the minimum town gas specifications in China of greater than 3,500 kcal/m^3 and less than 10 percent carbon monoxide.

3. Some have recommended that the gas be methanated to increase heating value and reduce the carbon monoxide content.20/ But that involves a very expensive catalyst and an exothermic reaction, and the gas needs to be sulfur free. Actually, the top gas from a two stage gasifier is already methane rich, while the bottom gas is mainly hydrogen and CO; by combining them, the rich gas is diluted. A better option, therefore, would be to convert the bottom gas from the two stage gasifier to ammonia or methanol. The higher value top gas could be used for town gas use. This approach should be investigated further.

20/ Methanation is a reaction of hydrogen and carbon monoxide into methane (and water) to get rid of the oxygen.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Assumptions for Town Gas Economic Analyses

1. Average incremental costs were estimated for each option, on both a volume and calorific basis. The coke oven and Lurgi gasification installations are relatively large plants, whereas the vertical retort and two stage gasification are small plants. Coke ovens could be as small as the vertical retort plant size; however, the gas cost would be higher than that of large coke oven plants.

2. Coke Oven. The analysis here assumes that investments are made in the coke plants that use sized steam coal in gas producers to supply the low heating value gas to heat the coke oven, thus releasing the maximum amount of higher calorific gas for town gas. The gas producers are fed sized steam coal. It assumes the purchase of unsized steam coal, which is then screened; the fines are burned in a pulverized coal boiler to supply the plant steam and electricity requirements.

3. Vertical Retorts. As with coke ovens, vertical retorts have special feed coal requirements, although they are not as limiting as metallurgical coal; the price of coal for vertical retorts is therefore higher than generic steam coals. Vertical retorts are used only at small-scale plants.

4. Two Stage Gasifier. Lump steam coal is fed to a moving bed gasifier operated at atmospheric pressure. It produces a gas which has a heating value of only 2500-3000 kcal/m^3 and contains 25-30 percent carbon monoxide. investment and operating costs were increased in this option to reflect the fact that modifications to this technology would be needed to surmount potential operating problems and to assure environmental controls.

5. Modern Coal Gasifier. A modern Lurgi gasifier is used here as the prototype. It uses steam coal, with the fines screened and used in utilities. It is feasible only at large scale. The capital cost is high because it is a process at high pressure, requiring an oxygen plant.

Table 1

CHINA

Efficiency and Environmental Impact of Coal Use

Economic Analysis of Alternatives

(Million Yuan; Dec. 1989 prices)

	Coke Oven Gas	Retort Gas	Fixed Bed Gasifier (Oxygen blown)	2 Stage Gasifier
A. Costs:				
a. Capital investment	130.00	190.00	1,000.00	95.00
b. Operating costs: /_1				
Retort coal	-	38.40	-	-
Sized steam coal	35.76	-	-	12.89
Steam coal	-	-	99.00	-
Utility steam coal	-	6.12	33.01	-
Lobor	1.20	1.20	3.01	1.20
O&M and G&A	6.40	9.50	50.00	9.50
Subtotal	43.36	55.22	185.02	23.59
B. Products: /_3	4.38	42.83	39.60	1.49

/_1: Price of coal:
Retort coal- 200 Yuan/ton;
Steam coal (mixed lump & fines)- 150 Yuan/ton;
Sized steam coal- 175 Yuan/ton.

/_2: Includes electricity at 0.50 Yuan/KWhr, representing shortage cost.

/_3 The main product of the coke oven is coke (revenues not shown). The Lurgi and two stage gasifier produce tars and oils. The vertical retort produces retort coke.

Table 2
Efficiency and Environmental Impact of Coal Use

Economic Analysis For Coke Oven Gas

(Million Yuan; Dec. 1989 prices)

Years	Costs Capital	Costs Operation	Costs Total	Products /_1	Net cost stream	Rich gas released (mln m3) /_2	Total energy (bln KCAL) /_3	Volume price (Ÿ/m3)	Energy price (Y/m KCAL
1	39.00		39.00		(39.00)				
2	65.00		65.00		(65.00)				
3	26.00		26.00		(26.00)				
4		28.18	28.18	2.85	(25.33)	257.40	1,081.1		
5		39.02	39.02	3.94	(35.08)	356.40	1,496.9		
6		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
7		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
8		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
9		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
10		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
11		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
12		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
13		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
14		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
15		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
16		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
17		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
18		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
19		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
20		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
21		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
22		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
23		43.36	43.36	4.38	(38.98)	396.00	1,663.2		
Total	130.00	847.68	977.68	85.63	(892.1)	7,741.8	32,515.6		
NPV 10%					(346.29)	2,413.7	10,137.6	0.14	34.16
12%					(301.50)	1,994.8	8,378.3	0.15	35.99
15%					(250.84)	1,530.8	6,429.6	0.16	39.01

/_1: Products include tars and light oils.
/_2: Assume 1.2 million cu. m/day * 330 days/year = 396.0 million cu. m/year.
/_3: Assume 4,200 KCAL/ cu. m.

Table 3

Efficiency and Environmental Impact of Coal Use

Economic Analysis For Retort Gas

(Million Yuan; End 1989 prices)

Years	Costs: Capital	Costs: Operation	Costs: Total	Products	Net cost stream	Rich gas released (mln m3) /_1	Total energy (bln KCAL) /_2	Volume price (Y/m3)	Energy price (Y/m KCAL
1	57.00		57.00		(57.00)				
2	95.00		95.00		(95.00)				
3	38.00		38.00		(38.00)				
4		35.89	35.89	27.84	(8.05)	53.60	225.1		
5		49.70	49.70	38.55	(11.15)	74.30	312.1		
6		55.22	55.22	42.83	(12.39)	82.50	346.5		
7		55.22	55.22	42.83	(12.39)	82.50	346.5		
8		55.22	55.22	42.83	(12.39)	82.50	346.5		
9		55.22	55.22	42.83	(12.39)	82.50	346.5		
10		55.22	55.22	42.83	(12.39)	82.50	346.5		
11		55.22	55.22	42.83	(12.39)	82.50	346.5		
12		55.22	55.22	42.83	(12.39)	82.50	346.5		
13		55.22	55.22	42.83	(12.39)	82.50	346.5		
14		55.22	55.22	42.83	(12.39)	82.50	346.5		
15		55.22	55.22	42.83	(12.39)	82.50	346.5		
16		55.22	55.22	42.83	(12.39)	82.50	346.5		
17		55.22	55.22	42.83	(12.39)	82.50	346.5		
18		55.22	55.22	42.83	(12.39)	82.50	346.5		
19		55.22	55.22	42.83	(12.39)	82.50	346.5		
20		55.22	55.22	42.83	(12.39)	82.50	346.5		
21		55.22	55.22	42.83	(12.39)	82.50	346.5		
22		55.22	55.22	42.83	(12.39)	82.50	346.5		
23		55.22	55.22	42.83	(12.39)	82.50	346.5		
Total	190.00	1,079.55	1,269.55	837.33	(432.2)	1,612.9	6,774.2		
NPV 10%					(234.4)	502.9	2,112.1	0.47	110.98
12%					(216.08)	415.6	1,745.5	0.52	123.79
15%					(194.28)	318.9	1,339.5	0.61	145.03

/_1: Assume 0.25 million cu. m/day * 330 days/year = 82.5 million cu. m/year.
/_2: Assume 4,200 KCAL/ cu. m.

Table 4

Efficiency and Environmental Impact of Coal Use

Economic Analysis For Oxygen Blown, Fixed Bed Gasifier

(Million Yuan; End 1989 prices)

Years	Costs: Capital	Costs: Operation	Costs: Total	Products	Net cost stream	Gas roduction (mln m3) /_1	Total energy (bln KCAL) /_2	Volume price (Y/m3)	Energy price (Y/m KCAL
1	100.00		100.00		(100.00)				
2	350.00		350.00		(350.00)				
3	250.00		250.00		(250.00)				
4	200.00		200.00		(200.00)				
5	100.00		100.00		(100.00)				
6		120.26	120.26	25.74	(94.52)	429.0	1,716.0		
7		166.52	166.52	35.64	(130.88)	594.0	2,376.0		
8		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
9		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
10		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
11		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
12		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
13		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
14		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
15		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
16		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
17		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
18		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
19		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
20		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
21		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
22		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
23		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
24		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
25		185.02	185.02	39.60	(145.42)	660.0	2,640.0		
Total	1,000.00	3,617.14	4,617.14	774.18	(3,843.0)	12,903.0	51,612.0		
NPV 10%					(1,499.2)	3,324.7	13,298.7	0.45	112.73
12%					(1,314.1)	2,650.4	10,601.7	0.50	123.95
15%					(1,105.1)	1,929.2	7,716.9	0.57	143.21

/_1: Assume 2.0 million cu. m/day * 330 days/year = 660.0 million cu. m/year.
/_2: Assume 4,000 KCAL/ cu. m.

Table 5

Efficiency and Environmental Impact of Coal Use
Economic Analysis For Two Stage Gasifier

(Million Yuan; End 1989 prices)

Years	Costs: Capital	Costs: Operation	Costs: Total	Products	Net cost stream	Gas roduction (mln m3) /_1	Total energy (bln KCAL) /_2	Volume price (Y/m3)	Energy price (Y/m KCAL
1	28.50		28.50		(28.50)				
2	47.50		47.50		(47.50)				
3	19.00		19.00		(19.00)				
4		15.33	15.33	0.97	(14.36)	51.5	154.4		
5		21.23	21.23	1.34	(19.89)	71.3	213.8		
6		23.59	23.59	1.49	(22.10)	79.2	237.6		
7		23.59	23.59	1.49	(22.10)	79.2	237.6		
8		23.59	23.59	1.49	(22.10)	79.2	237.6		
9		23.59	23.59	1.49	(22.10)	79.2	237.6		
10		23.59	23.59	1.49	(22.10)	79.2	237.6		
11		23.59	23.59	1.49	(22.10)	79.2	237.6		
12		23.59	23.59	1.49	(22.10)	79.2	237.6		
13		23.59	23.59	1.49	(22.10)	79.2	237.6		
14		23.59	23.59	1.49	(22.10)	79.2	237.6		
15		23.59	23.59	1.49	(22.10)	79.2	237.6		
16		23.59	23.59	1.49	(22.10)	79.2	237.6		
17		23.59	23.59	1.49	(22.10)	79.2	237.6		
18		23.59	23.59	1.49	(22.10)	79.2	237.6		
19		23.59	23.59	1.49	(22.10)	79.2	237.6		
20		23.59	23.59	1.49	(22.10)	79.2	237.6		
21		23.59	23.59	1.49	(22.10)	79.2	237.6		
22		23.59	23.59	1.49	(22.10)	79.2	237.6		
23		23.59	23.59	1.49	(22.10)	79.2	237.6		
Total	95.00	461.18	556.18	29.13	(527.1)	1,548.4	4,645.1		
NPV 10%					(214.14)	482.7	1,448.2	0.44	147.86
12%					(188.16)	399.0	1,196.9	0.47	157.21
15%					(158.62)	306.2	918.5	0.52	172.70

/_1: Assume 0.24 million cu. m/day * 330 days/year = 79.2 million cu. m/year.
/_2: Assume 3,000 KCAL/ cu. m.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Options in Major Coal-Using Industries 1/

A. Introduction

1. The steel, ammonia, and building materials industries are all coal-intensive industries. Hence, reducing their energy intensity could also offer important gains to the economy. The major issues in regard to coal use in these industries are discussed in this annex. Some central themes emerge: the small-scale of industry and the older technology used in many plants; the pace of modernization and technology diffusion; insufficient investment in beneficiation to improve the quality of inputs; the unresponsiveness of commodity and material allocation systems; inefficient plant designs and low asset utilization; and lack of opportunity for fuel diversification.

B. Issues and Options in Steel Production

Background on Steel-Making and Industry Structure

2. Steel production is an energy intensive industry and almost totally coal-based. In 1988, the Chinese steel industry consumed over 51 million metric tons of metallurgical coal (coking coal) and 30 million tons of steam coal. The large state enterprises in the Chinese steel industry appear to have significant authority and resources for modernization. New steel mills possess state of the art technology. There are 14 large scale plants (each with production capacities over 1 million tons), representing about 60 percent of total production (45 million tons in 1988). Medium to small scale plants produce the remainder. Because of steel shortages, China also imports over 20 million tons of steel products.

3. The steel making process involves converting iron ore to finished steel products. This requires removing oxygen and other impurities from the iron ore, adding carbon and trace metals, and finally producing the finished steel in marketable shapes. The heart of steel making is the iron making process, which traditionally includes coke ovens for coking and blast furnaces for converting iron ore to molten iron, commonly called pig iron.

4. Coke is produced in coke ovens which indirectly heat and devolatize coal in the absence of oxygen.2/ The ovens are operated batchwise at

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1/ This annex is based on analyses by D. Simbeck and contributions by K. Constant and M. Fog. It has also benefited from the data and analyses provided in Working Papers Nos. 3 and 4 by the Energy Research Institute, SPC, and the China General Coal Utilization Corporation.

2/ Coke is bituminous coal from which the volatile constituents have been driven off by heat so that the fired carbon and ash are fused together.

atmospheric pressure: coal is charged into the hot oven; then, after about 18 hours, the red hot coke is pushed out of the oven and directly quenched with water. Coke ovens represent the largest and most important energy source in steel making--about 60 percent of the total energy used in Chinese steel making.3/ The coking process also produces several by-products: a large amount of medium heating value fuel gas; and tars and oils which are used in chemical production. The relatively high heating value of coke oven gas (4,200 kcal/m^3) can be used in place of premium fuels such as natural gas.4/

5. The most important properties of coke are large size and strength. In the blast furnace, preheated air is injected into a moving bed of sized iron ore, limestone and coke. The function of the coke is unique--it supplies the energy and strength to support the heavy moving bed plus the reducing agent, carbon, to remove the oxygen from the iron ore. Blast furnaces cannot process iron ore fines; therefore, most iron ore undergoes pelletizing and sintering to increase particle size by agglomeration.

6. The three basic processes in refining iron and scrap into raw steel are: the open hearth furnace; the basic oxygen furnace (BOF); and electric arc furnaces (EAF). The open hearth furnace is an antiquated process which has been replaced by BOF in most countries. In China, about 17 percent of raw steel is still produced by open hearth furnaces; in contrast, the last open hearth furnace in Japan was shut down over ten years ago. The larger modern Chinese steel mills use BOF to process the molten iron into raw steel.

7. Electric arc furnaces (EAF) are used in western steel industries to melt scrap--commonly in nonintegrated "mini" mills. These mills have become a very competitive force in the world steel industry. As there is little available scrap in China, EAF is mostly used for production of specialty steels in medium to small nonintegrated steel mills; they are usually less efficient than large integrated steel plants. EAF accounts for about 20 percent of Chinese steel production.

8. Finishing of steel generally involves solidifying the molten steel into a primary shape, followed by rolling or stamping into a finished product. A modern method is continuous casting, where molten steel is continuously poured into molds that solidify the steel into primary shapes, which can then be fed directly into a secondary rolling process. Continuous casting presently represents about 15 percent of Chinese finished steel production, but is projected to grow significantly in the future. In comparison, over 75 percent of steel produced in Japan is by continuous casting.

Conservation of the Coking Coal Supply

9. Metallurgical or coking coals used in coke ovens consist of a blend of high quality bituminous coals with special caking properties to produce large and strong agglomerated coke particles. The metallurgical coal blends

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3/ The percentage rises to almost 90 percent with modern steel making processes.

4/ Refer to Chapter VII and Annex 8 for a discussion of the role of coke oven gas as town gas.

should be as low as possible in ash and sulfur to improve the efficiency of the blast furnace. Therefore, only low sulfur coals are used for metallurgical purposes, and essentially all are washed to reduce ash.

10. Despite large coal reserves, there is a shortage in China of the highest quality low and medium volatile coking coals which normally account for 30-40 percent of the final coking coal blend fed to the coke oven. Some "met" coal has a high ash content; therefore, it must be extensively cleaned to reduce ash. In addition, reserves of prime met coal are not located in major steel producing areas, thus involving transport over long distances. The major steel mills in Anshan and Shanghai appear to be constrained in coke production (and thus steel production) by sometimes problematic delivery of high quality, low volatile coals from Shanxi province.5/ Even worse, some of the best metallurgical coals in Shanxi are being processed locally in small, inefficient beehive coke ovens (which are also very polluting). Beehive ovens produce significantly less coke per unit of coking coal feed than a modern coke oven. Annex 11 discusses ways to conserve coking coal by improved washing techniques, better washery utilization and better scale of plants.

Energy Rationalization

11. The key ratio in evaluating the energy efficiency of steel plants is the coke rate--kg of coke/ton of pig iron. The average rate for the Chinese steel industry is 550 kg/ton (1988); that rate reflects reliance on smaller, older blast furnaces and the lack of scrap steel in the economy. Still, the industry's performance is relatively good, considering the constraints cited. As a comparison, Table 1 shows indicative coke rates in various countries, representing both modern and aging steel industries.

Table 1: TYPICAL COKE RATES IN VARIOUS COUNTRIES, 1987 /a
(kg coke/ton pig iron)

Brazil	500
France	472
Japan /b	477
South Korea	460-470
UK	484
US	526

/a Coke rates at individual plants are often proprietary. Therefore, these data are indicative only.
/b Flagship plants in Japan can have rates of 400-450.

Source: Coal Consumption (Japan), 1989, and Bank staff data.

5/ This has led to the import of coking coal into East China.

12. The potential savings to China from employing measures to reduce unit coke requirements are large. The most significant short term solution for lowering the coke rate is not technological but operational--injecting pulverized steam coal in the tuyeres of the furnace, thus providing heat and "reducing gas" (hydrogen and CO).6/ Some Chinese steel plants are already using this well-established technique and should be encouraged to do so further. For each ton of steam coal in the tuyeres, one can save 1.33 tons of met coal. The objective is to reduce coke to the minimum mechanically required to support the iron ore bed in the furnace. This technique could reduce coking coal requirements by 20-30 percent.

13. Greater efficiency over the medium to long term will come with continued modernization and process integration. It will take time to phase out the still significant number of plants using open hearth furnaces, but as this occurs energy intensities should fall. Further inroads by continuous casting has the potential to reduce the current raw steel to finished steel rate by over 10 percent.

14. The high coal requirements per ton of finished steel in China also reflect a lack of scrap steel and the low iron content in the iron ore. The lack of scrap reflects a less mature economy. The energy needed to convert scrap to finished steel is significantly less than from iron ore--about one-fifth. Considering the low iron content being used in China, increased use of scrap in place of iron ore has the potential to reduce coal requirements per ton of finished steel by 20-50 percent.7/ It is unlikely that large supplies of scrap steel will develop in the near future. There are reports, though, that the existing central scrap collection and distribution system does not work well, inhibiting the flow of useful scrap which could be made available. Measures should be taken to enhance the availability of scrap, to the extent possible, in view of the potential economies. Authorities might also consider the import of scrap, as prices on world markets are very low.

15. An action of secondary importance would be improving the iron content of iron ore used in the industry; most steel industries worldwide use iron ore with over 60 percent iron content. The average FE content of iron ore in China is only 35-40 percent, which can affect blast furnace productivity and energy requirements, if the iron ore is not properly beneficiated (which entails significant processing costs). Even when beneficiated, average iron content in China is about 52 percent. Because of these problems, China already imports about 10 percent of its iron requirements for steel making. In addition, most iron ore reserves are located far from major steel plants, thus adding to the transport burden in the country.

6/ The process is called PCI, pulverized coal injection.

7/ Use of scrap is key to improved efficiency of steel plants in the United States, for example. The large supplies of scrap in the United States reflect an already developed economy and aging infrastructure, however.

Technology Change

16. In the longer term, a technological shift to direct reduction in the world steel industry is likely to occur, moving away from coke ovens and blast furnaces, although this process currently accounts for only 1 percent of world iron production. Most direct reduction processes involve the conversion of iron ore pellets by "reducing" (removing oxygen) the pellets via a reaction with synthesis gas (hydrogen and CO) in moving or fluidized bed reactors. A compelling reason for China to investigate this technology is its lack of sufficient prime met coal and its considerable coal gasification experience.

17. Essentially all reduction systems presently use natural gas (via steam/methane reforming) to generate the required hot synthesis gas. The Chinese metallurgical industry could make "syngas" from coal--via water gas reactors, an existing technology in China. A water gas reactor could be combined with a commercially-proven reduction process to develop an advanced steel/iron making capability that also assures good pollution control. The feasibility and economics of this longer term option should be considered and evaluated in planning a long term strategy for technology adaptation in the Chinese steel industry.

Projections to the Year 2000

18. Table 2 outlines the material and energy requirements in the steel industry in 1988 and projected to the year 2000. It should be noted that the projected coal requirements per ton of finished steel reflect the various factors discussed above as well as some general inefficiencies. Electricity and steam coal uses may be overstated; over the last few years, there has been a major move by the steel mills to generate more electricity.8/

19. Key to achieving a coke rate of 500 by 2000, an increase in efficiency of almost 10 percent, are the following measures: increased steam coal injection into the blast furnace and increased continuous casting. The projections show lower efficiency gains than what could potentially be achieved due to assumed continued shortages of steel, necessitating continued use of older, less efficient processes.

Pollution Control

20. In regard to pollution control, the metallurgical industry in China is active in trying to improve emission problems associated with the industry. The modern coke ovens in China appear to have less emissions than coke ovens in some Western countries. The lower labor cost in China makes the cost of repair and maintenance of the coke oven doors less expensive. In addition, the newer coke ovens use modern coal charging, pushing and quenching equipment, keeping these sources of pollution relatively low. Water pollution from coke oven plants may be a bigger concern. While it appears that many coke ovens have biological treatment, it is unclear how much is treated, to what

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8/ For example, Baoshan Steel recently completed a 500 MW power plant which apparently will supply all the plant's electric power needs; surplus power is to be sold to neighboring Shanghai.

level, and where it is discharged. Finally, the long term environmental concern in regard to coke ovens should be improved worker health, a worldwide problem because coke oven emissions contain high levels of polynuclear aromatics (PAH), which are known carcinogens.

Table 2: OVERALL MATERIAL AND ENERGY IN CHINA STEEL INDUSTRY

	Units	1988	2000
Metal			
Iron ore (@ only 40 percent wt Fe)	M ton	130	210
Pig iron	M ton	65	100
Raw steel	M ton	59	90
Finished steel	M ton	45	72
Coal/Coke			
Metallurgical coal	M ton	51	70
Coke	M ton	36	50
Coke rate	kg coke/ton pig iron	550	500
Steam coal to power	M ton	28	45
Steam coal to blast furnace	M ton	2	8
Purchased electricity	billion kWh	36	51
Steam equivalent in electricity	M ton	17	24
Actual coal	M ton	81	123
Actual coal + coal equivalent in electricity	M ton	98	147
Energy Rate			
Actual coal/finished steel		1.8	1.7
Equivalent total coal/ finished steel		2.2	2.0

Source: Calculations by study team based on data provided by MMI.

21. Small primitive coke ovens (beehive) are very bad polluters (both air and water). They have been banned from parts of densely populated East China, but are still frequently found in mining areas in Shanxi and other provinces. They account for about 10 million tons of coke production, compared to total production in 1988 of 36 million tons. Because much of this coke is sold on the negotiated market, it appears to be an extremely profitable small scale industry; however, the plants can be significant polluters in local areas, and they waste prime coking coal (10-20 percent in some plants). Strong measures need to be taken to eliminate this inefficient and polluting form of production.

22. The worst air pollution at steel mills appears to be particulates from steam coal boilers and sintering plants. The sintering plants are probably the worst offenders; in addition, their SO_2 emissions are likely to be higher, and they usually do not have very high stacks. Absolute emission levels from the steel industry are not available. According to the Ministry of Metallurgical Industry, the sulfur content of steam coal used in the steel industry is 1-2 percent. Metallurgical coal sulfur content is generally less than 0.7 percent, and most of this sulfur is captured in the blast furnace slag. Water pollution--from acid wastes in steel cleaning--may be the biggest environmental problem in the industry.

C. Issues and Options in Ammonia Production

Background on the Industry

23. The chemical industry in China consumed over 45 million metric tons of coal in 1987.9/ Coal represented over 55 percent of the total energy used in the chemical industry. The chemical industry consists of numerous specific chemical production processes which generally use coal for steam and power generation. The major use of coal in actual chemical production--accounting for about 20 million tons--is in the manufacture of ammonia.

24. China produced over 12 million metric tons of nitrogen (N basis) in 1987. A breakdown of production based on the feedstock is shown below:

Table 3: NITROGEN PRODUCTION (1987)

Raw material	N (million tons)	%
Coal and coke	7.5	62
Natural gas	2.6	22
Fuel oil and naphtha	1.9	16
Total	12.0	100

Solid forms of final ammonia (NH_3) include primarily ammonium bicarbonate, urea, and ammonium nitrate. Ammonium bicarbonate represents more than half of production. Typically produced in small coal or coke based plants, it is a poor product in terms of nitrogen content and stability (it degrades quickly and therefore can be used only close to where it is produced). Urea, which is second in production, is the favored form because of its higher nitrogen content and good stability.

25. The industry has three general types of ammonia plants, based on ammonia capacity, as follows:

9/ This includes coal used for utilities.

(a) Large-scale (≥300,000 tpa)--19 plants (18 producing urea)

(b) Medium-scale (40,000-150,000 tpa)--54 plants

(c) Small-scale (5,000-30,000 tpa)--est. 1,200 plants

The large plants are world class, based on imported technology. About 12-13 plants are based on natural gas, although there are several plants based on residual oil and coal gasification.10/ Unfortunately, however, some of the plants operating on natural gas are only operating at 60-70 percent capacity or are shut down during part of the year because of problems in obtaining natural gas supplies, apparently caused by institutional as well as perhaps technical reasons. The low utilization of such plants represents a serious loss of efficiency (see para. 28 below).

26. An estimated 50 percent of the medium-sized ammonia plants use oil or natural gas; the other half use anthracite or coke. The majority of small-sized plants are anthracite or coke based and produce ammonium bicarbonate.11/ Many are quite old, very small and inefficient; plants of 5,000 tpa are uneconomic. Some represent major environmental problems (generating both air and water pollution). Yet they represent convenient decentralized production, essential to local agriculture, given infrastructure and transport problems.12/

27. Many of the small ammonia plants in China were originally based on coke, but have now converted to sized anthracite or briquettes made from anthracite fines due to the high price and shortage of coke (used primarily in steel making). Consequently, there has been increased demand for sized anthracite in ammonia production, in some cases competing with the residential sector for good quality anthracite.

Efficiencies of Plant Technologies

28. The energy efficiencies of these plants vary widely. Coal use in small-scale ammonia production is about 2.7 tons of coal per ton of coal-based NH_3 or about 17.5 million kcal per ton NH_3. With upgrading and better management, it should be possible to reduce energy requirements of some of these plants by 25-30 percent. A plant based on modern coal gasification requires about 1.7 ton coal/ton NH_3 or about 11 million kcal per ton. Most dramatically, though, a modern natural gas-based ammonia plant requires only 7-8 million kcal/t NH_3. The efficiency of natural gas is due to the fundamental

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10/ The Lucheng plant in Shanxi is based on modern Lurgi coal gasification technology. There appear to be operating problems, however.

11/ Ammonia-based fertilizer is produced from coal by using a cyclic producer gas/water gas reaction. The process produces hydrogen from the coal and reacts the hydrogen with nitrogen to produce ammonia. Coke and anthracite are favored over bituminous coal for this application because they produce less fines, methane and waste liquid tars and phenols in the cyclic reaction.

12/ Indeed, some old plants which were shut down in the late 1970s/early 1980s have been recommissioned in the last five years in order to meet growing demand.

technical fact that it has a higher hydrogen content and less sulfur or other by-products.

29. At Table 4 are estimates of the costs of ammonia production via three generic technologies:

(a) a large natural gas-based plant using modern steam methane reforming;

(b) a large coal-based plant using modern coal gasification technology (e.g., slurry fed, entrained flow coal gasification) gasifying low cost steam coal;

(c) a small coal-based plant involving cyclic water gas reaction of sized anthracite (based on an economic size plant of 30,000 tpa).

These three cases represent extremes relative to both feedstock and technology. The unit capital costs of both the small and large coal-based ammonia plants are assumed to be the same.

Table 4: COMPARATIVE COSTS OF AMMONIA PRODUCTION

Feedstock	Natural Gas		Steam Coal		Sized Anthracite	
Plant Size	Large 1,000 tpd or 300,000 tpa		Large 1,000 tpd or 300,000 tpa		Small 100 tpd or 30,000 tpa	
Feedstock cost	Y 0.45/m_3 Y 50/M kcal		Y 150/t Y 27/M kcal		Y 200/t Y 45/M kcal	
Utilities fuel	Natural gas		Steam coal		Steam coal	
Gas generator	Steam reforming		Entrained flow coal gasifier		Cyclic water gas reactor	
Capital cost (yuan per annual ton of NH_3)	1,500		3,000		3,000	
Assumptions (yuan/ton)						
Feedstock	650 m_3/t	293	1.15 t/t	173	1.4 t/t	280
Utilities	350 m_3/t	158	0.55 t/t	83	1.3 t/t	195
O&M	7% of cap.	105	7% of cap.	210	8% of cap.	240
Capital Charges	15% of cap.	225	15% of cap.	450	15% of cap.	450
Ammonia Cost		780		915		1,165

30. The results show the potential advantages of natural gas-based ammonia production over coal-based production, especially in comparison with small anthracite-based plants. The unit cost of natural gas is 50 percent less. Table 4 also indicates that the unit cost of modern coal gasification, though higher than that of natural gas, is close to 30 percent less than that of small coal-based plants. Large modern plants based on natural gas or coal gasification, of course, require much more initial capital as well as foreign exchange for imports of technology.

Environmental Aspects

31. There are major differences in environmental effects from the three classes of ammonia plants. Large natural gas-based ammonia plants have minimal emissions. Large coal-based ammonia plants can be as clean, assuming state-of-the-art technology is used for sulfur recovery and waste water cleanup. Existing medium and small coal-based ammonia plants are causing environmental problems. Airborne emissions from these plants are generally associated with the steam coal used in stoker boilers for utilities at the plant, not from the coal gasification process itself; such emissions could be reduced by use of low sulfur coal with less fines. The biggest environmental problem at these plants, however, is liquid waste, which can be significantly reduced by use of biological treatment of waste water.

Options for the Future

32. Projected production in the year 2000 is 24 million tons of N, double 1987 production. It is unclear how much of that capacity will be based on natural gas versus coal. Coal-based production is still likely to represent 50-60 percent of capacity. Gains in efficiency will obviously come from expansion of natural gas-based plants. Two other measures are key: (i) rationalizing existing coal-based plants; and (ii) optimizing energy utilization in natural gas-based plants. Modern coal gasification is a longer-term option for large-scale ammonia production where natural gas is unavailable.

33. Rationalizing Anthracite-Based Fertilizer Plants. A number of measures could help to improve energy efficiency in anthracite-based plants. First, a program is needed to phase out the very small plants of 5,000 tpa and the most inefficient plants in the 10,000-15,000 tpa range. The more promising plants in the latter range (based on criteria such as plant condition, management and track record to date) could be upgraded to a more economic size (in the order of 30,000 tpa). Such a rationalization program would reduce the number of small plants from 1,200 to an estimated range of 700-800 and could improve energy efficiency overall by as much as 30 percent. Plant rationalization and technology upgrading could also improve energy efficiency in some of the medium and large size plants as well.

34. More uniformity and quality of coal feed would also improve plant operations and efficiency as well as environmental control. Many small to medium-sized plants are producing briquettes from anthracite fines as a feed-

stock for the gasifier.13/ Total briquette production has been estimated at 22 million tons per year, which accounts for some 60 percent of the coal feedstock for ammonia production. The cost and inefficiency of such briquetting appears to be high, however.

35. The production cost of carbonated lime briquettes, as produced in Jiangsu province, is cited as Y 80 per ton. Economic costs are probably more than double that. The techniques used for briquetting are identical to those used in the West, although carbonated lime as a binder is unique to China. Operating techniques at briquetting plants appear to be suboptimal. Plant equipment at sites visited had minimum controls, producing briquettes of poor and quite variable quality. During curing, briquette strength is increased from 5 kg to 45 kg, indicating a 65 percent conversion to calcium carbonate.14/ Complete conversion to calcium carbonate would give a cured strength of 80 kg. Good process control in such briquetting plants should make it possible to achieve cured strengths of about 70 kg.

36. The opportunity cost of using anthracite is also high because of the need for anthracite and anthracite fines in making briquettes for cooking in the residential sector. Very high binder proportions are required (28 percent at one large plant) to produce strong briquettes with a target strength of >50 kg for ammonia production. Because of the high mineral matter added as binder, a low ash feedstock is needed.15/ The anthracite feedstock sometimes has an ash content of 10-14 percent. Use of such high quality anthracite is badly needed in the domestic sector as well. Therefore, improved briquetting techniques would help to reduce anthracite requirements.

37. Improving Energy Utilization in Natural Gas-Based Plants. About one-third of the natural gas consumed in natural gas-based ammonia production is for utilities. This principally involves firing the gas to heat the steam methane reforming furnace. Low cost coal gasification--via simple gas producers--could be used in China to replace this use of natural gas, reducing natural gas requirements per ton of ammonia by one-third.16/

13/ The large price differential between lump anthracite and anthracite fines (there was a Y 50 difference in Jiangsu province in mid-1989) has encouraged briquetting.

14/ In curing, the briquettes are put in contact with gases rich in CO_2 at a temperature of 80°C for 36 hours. The curing time of 36 hours is regarded as excessively long; in the laboratory it can be achieved in 6 hours. Lab performance is usually superior to operating plant performance due to tighter control over important parameters such as flow rates, moisture content and temperatures. In addition, the poor quality of the briquettes leads to high degradation to fines in the curing chamber, affecting the efficiency of briquette to gas contact.

15/ When mixed with lime, low ash anthracite helps to increase the ash fusion temperature and improve briquette strength (thus avoiding excessive clinkering in the hot zone of the gasifier). Moreover, at fixed carbon content below 45 percent, gasification efficiency is markedly reduced.

16/ Gas producers are commonly used throughout China already.

38. Modern Coal Gasification. In areas where natural gas is not available, large ammonia plants based on modern pressurized oxygen-blown coal gasification technologies, such as slurry fed entrained flow gasification, offer potential in the longer term. These technologies have key advantages over small cyclic water gas reactors as follows: (a) they use relatively low cost steam coal; (b) they can use fines (whereas cyclic gas producers can only use lump coal); (c) they would produce a better product; and (d) they are less polluting.

39. An area for research and development is modern coal gasification combined with sulfur production for phosphate fertilizer.17/ There is a shortage of sulfur and sulfuric acid, and prices are high. The shortage of sulfur affects the development and availability of phosphate fertilizer. Chinese authorities might consider the development of modern coal gasification plants for ammonia production in areas of China with high sulfur coals. These plants could supply a large, probably cost effective source of sulfur as well as ammonia.

D. Issues and Options in Building Materials

40. Building materials include cement, gypsum, bricks, tiles, glass and other mineral-based building materials. In this study, cement and brick kilns are considered as they are large consumers of coal. Chinese authorities are trying to improve the efficiency and environmental control of the cement and brick industries, in particular for the many small scale plants scattered in towns and villages throughout the country. Improvements will involve the transition over time to better scale and modern processes.

Cement

41. Cement production is a significant coal consumer--28 million tons in 1987. Coal represents about 80 percent of the energy consumed in the cement industry. Cement plants appear to be the most polluting of building materials industries. At the same time, the lives of cement plants are very long, 25-30 years.

Technology and Industry Structure

42. China produces a wide range of major cement products of varying degrees of strength. There are two principal technologies in cement production: the rotary kiln and the older shaft kiln; the latter is commonly used in small-scale plants. Rotary kilns comprise two basic types: the modern, more efficient dry process and the outdated wet process. The contributions to production by different types of technology are shown below:

17/ Sulfur is converted to sulfuric acid for use in converting phosphate rock into superphosphate fertilizer.

Table 5: CEMENT PRODUCTION, 1987

	Million tons	%
Rotary Kilns		
Dry and semi-dry process	14	7.2
Wet process	20	10.8
Subtotal	34	18.0
Shaft Kilns	152	82.0
Total	186	100.0

43. The industry can be divided into three categories of plants:

(a) large and medium size plants using rotary kilns, with annual capacities of more than 200,000 tpa;

(b) small scale plants generally using mechanized and semi-mechanized shaft kilns, with annual capacities of up to 200,000 tpa; and

(c) very small, primitive plants using manual shaft kilns and often crude pits, with annual capacities of less than 20,000 tpa.18/

Small size plants using shaft kilns dominate cement production. They are owned by provinces, counties and municipalities; very small plants are normally operated by towns and villages. The large and medium size plants (about 63 plants) are usually controlled by the central government. The quality of cement from vertical kilns is generally much lower than that of rotary kilns. The very small plants, usually in rural areas, produce a very low strength cement.

44. The trend in structure is presented in Table 6. The government's announced strategy since the early 1980s has been to increase the share of production by modern methods and larger scale plants. In fact, though, the trend over the past ten years has been toward greater reliance on small scale production. The percentage share of larger, more modern plants has decreased.

45. Impediments to development of larger scale plants include: the bureaucratic investment approval system for larger plant investments; a lack of commitment of resources, including foreign exchange, to import equipment needed for large modern plants; interprovincial trade barriers; and lack of infrastructure, impeding the development of larger markets which could spur better scale of plants. In order to meet the increasing needs of local construction and avoid long approval processes, the number of small scale plants

18/ World Bank Cement Industry Review, 1985.

in rural and semi-rural areas has grown by almost 16 percent over the last 10 years, faster than investment in modern plants. These small plants require little capital, and are able to sell their products on the free market, often making them profitable ventures due to the severe shortage of cement. Yet the technologies are backward, the cement product is generally inferior, and energy efficiency is poor.

Table 6: CEMENT PRODUCTION: STRUCTURAL TRENDS
(million tons)

	1980	%	1983	%	1985	%	1987	%	Avg. annual growth
Large/med. plants	25.5	32	27.2	25	31.6	22	34.2	18	4.2%
Small scale plants	54.4	68	81.1	75	114.4	78	152.0	82	15.8%
Total	79.9	100	108.3	100	146.0	100	186.2	100	12.9%

Source: State Bureau of Building Material Industry and Working Paper No. 3, Energy Research Institute, SPC.

Energy Efficiency

46. Energy efficiency is a problem with all classes of plants, but there is a lot of variation among plants. According to Chinese authorities, mean energy consumption of large enterprises operating rotary kilns is 1,400 kcal/kg clinker. Energy consumption using the dry process averages 1,200 kcal/kg in China.19/ In comparison, modern, world-class dry process kilns can be as low as 750 kcal/kg of clinker, 40 percent lower than the average in China. The potential for conservation is therefore obviously large. Those enterprises using the wet production method consume an average of 1,500 kcal/kg clinker.

47. Rotary Kiln. In the dry process, the raw materials are ground, blended and introduced into the kiln in the dry state.20/ In the wet process, the feed material is introduced as a slurry consisting of about 30-40 percent water. Water has to be evaporated in the kiln; hence this process is less fuel efficient than the dry process. Larger wet process units can be converted to either dry or semi-dry processes, thereby realizing energy savings. Most such conversions also increase capacity.

19/ These numbers may include energy use for ancillary activities.

20/ The conventional raw materials for cement manufacture are predominantly limestone blended with shales and iron ore, as needed, to assure adequate quantities of alumina, silica and iron oxides in the kiln feed material.

48. The dry process kiln lends itself very well to the incorporation of energy efficient preheater and precalciner equipment at the combustion gas exhaust of a kiln; preheater/precalciners utilize cyclone dust collectors, which provide a degree of built-in automatic dust collection. Precalciners are also more efficient in absorbing SO_2 from combustion gases. There are a few kilns in China with preheater or precalciner investments; most are in the experimental stage or represent pilot plants. Lack of modern instrumentation and control systems at plants is also a problem, making it difficult to apportion raw materials and maintain proper chemical balance.21/

49. Shaft Kilns. Chinese authorities state that the majority of plants use vertical kilns with daily productivity of less than 1,000 tons. Of about 6000 vertical kilns in China, 60 percent are mechanical vertical kilns (1987 data), which offer better efficiency and quality of product than traditional kilns. Introduction of the mechanical vertical kilns has represented an important technological improvement in this type of plant. Average energy consumption of all shaft kilns is estimated at 1,156 kcal/kg of clinker; under proper conditions, it should be possible to operate mechanical vertical kilns at 900-950 kcal/kg clinker.

50. The shaft kiln is less efficient than the rotary kiln because drying and grinding of raw materials occurs in two separate operations, requiring more fuel and more power than simultaneous drying and grinding in a modern rawmill. Loss of materials through raw material handling and dust emissions is likely to be high. Quality control is actually more difficult in shaft kilns. If the composition of raw materials is not properly formulated, it causes unevenness in the feed bed and leads to poor distribution of combustion gases. Investments in scales simply to measure ingredients more carefully could improve the process. Finally, the design of shaft kilns does not lend itself to the very large production capacities of the rotary kilns.

51. Anthracite is the common fuel for shaft kilns, because of its low volatiles content. If the volatiles content of the coal is above 12 percent, the kilns may not be able to use it because coal combustion must occur in the kiln, rather than the fuel burning off as it rises. Another requirement is that the coal be as uniform as possible; otherwise, it affects combustion and distribution of combustion gases.

Use of Fly Ash

52. In the manufacture of pozzolanic and slag cements, fly ash can be used, conserving materials and reducing the cost of ash disposal.22/ There are many uses for this lower quality cement. The properties of concrete made with these blended cements are inferior to those of portland cement concrete, however, and may not be acceptable in normal concrete construction. Research is needed to deal with ways of overcoming these deficiencies with additives, admixtures or special mixing and curing, in order to spur greater use of coal ash.

21/ Electronic controls are desirable at large modern plants.

22/ Bottom ash is not used very much because it contains more unburned carbon and is harder.

Environmental Protection

53. The combination of fly ash from the coal and dust from the cement ingredients constitutes a significant environmental problem in cement production.

54. Rotary Kilns. Rotary cement kilns are fired with a central pulverized coal burner, and these generally use bituminous coal. The process is relatively insensitive to the ash and sulfur content of the coal. Most of the ash in the coal burned is entrained in the combustion gases, and some of the feed material and product dust is also entrained.23/ Rotary kilns in China often emit a dense white plume, indicating uncontrolled dust emissions. Up to 10 percent of the feed material probably escapes in this manner. Improved dust collection, therefore, would achieve both raw material and fuel savings. It should be economical to recycle the dust to the kiln system by installing recycle equipment.24/

55. All rotary kilns in China are supposed to be equipped with good pollution control equipment, but this is not generally the case. In practice, ESPs are being installed on new large plants, but little is being done for older plants, except where there is strong local pressure.

56. Worldwide, kiln designers can choose from either fabric filters and electrostatic precipitators for high performance, reliable dust collection. In China, the choice is limited to electrostatic precipitators for main kiln dust control. This is due to lack of proven fabrics with acceptable service lives to make the fabric filter choice attractive.25/ Fabric filters are presently utilized for dust removal in less demanding activities at cement plants, such as cleaning the air from grinding and mixing operations.

57. As a comparison, in the United States, many plants use fabric filters for dust control at the kiln's combustion gas outlet. In plants where ESPs are used, the gas leaves the kiln at about 600°F and is conditioned by water sprays to about 300°F to adjust resistivity for better collection efficiency. Dust emission control accounts for 7-8 percent of the plant investment and about 10 percent of operating and maintenance costs; the costs of pollution control are therefore significant.

58. Shaft Kilns The air and combustion gas velocity through the shaft kiln is much lower than in rotary kilns. Since the raw materials and usually the coal fuel are pelletized before being charged into the kiln, there is much less tendency for the raw materials to be entrained in the discharge gases. The problem in shaft kilns is more likely to be poor combustion. Installation

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23/ The combustion gases pass through the kiln in direct contact with the feed material as it is converted into "clinker" during its passage through the kiln.

24/ The consequent high alkali levels accruing in the clinker would have to be managed, however.

25/ Also see discussion in Chapter VI.

of recycling equipment on shaft kilns would realize fuel savings primarily but also some raw materials.

59. Electrostatic precipitators are supposedly required for dust emission control on larger shaft kilns.26/ But Chinese authorities note that older large and medium size plants cannot meet new environmental requirements. Most of them are equipped with primitive cyclone or water screen dust collectors. In any case, the authorities regard the older, smaller size shaft kilns as their biggest environmental problem, as little or no pollution control is undertaken. Resources permitting, these kilns could be equipped with good dust collection equipment.

Strategy for Improved Conservation and Pollution Control

60. The scope for conservation is clearly recognized by authorities in the building materials industry, and there is an articulated strategy. This includes:

(a) support for investments in large modern "dry process" rotary kilns;

(b) conversion of wet process plants to dry and semi-dry plants;

(c) renovation of small plants with the use of improved technologies; and

(d) phase-out of very small plants.

The problem is the lack of an incentive structure that fits the announced strategy, particularly when much of the investment is occurring at the provincial and county levels.

Projections to the Year 2000

61. Cement demand projected for the year 2000 is 300 million tons. The range of energy consumption could be 48-54 million tce depending on the average energy efficiency of the industry in ten years.27/ If part of existing capacity can be upgraded or the most inefficient plants phased out, average energy consumption could be pushed even lower.

Brick-Making Industry

62. China produces the equivalent of about 400 billion standard brick per year, most burned in coal-fired kilns. The majority of brick plants are owned and run by township and villages enterprises (TVEs). There has been a rapid increase in collective/semi-rural brick industries over the past ten years, due to the boom in the construction industry in both urban and rural areas and to the economic liberalization in rural areas. This boom has been described

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26/ The emission limit is 100-150 milligrams of dust per m^3 of gas discharged. This translates to a 90-98 percent removal efficiency.

27/ A range of 0.145-0.191 tce/ton of clinker for incremental production was used in this estimate.

as being like "bamboo shoots after a spring rain." Growth in brick production averaged 14.5 percent over the 1980-87 period, and the increase in local kilns jumped from 76 percent of production in 1980 to 90 percent in 1987. Table 7 below shows this trend:

Table 7: TRENDS IN BRICK PRODUCTION

Year	Total production (billion pieces)	Production by state enterprises	% of total Production
1980	153.7	38.2	25.0%
1984	249.9	41.2	16.5%
1987	399.1	39.5	9.8%

Source: Working Paper #3 "Industrial Coal Use," Energy Research Institute, State Planning Commission, August 1988.

63. The traditional clay bricks produced by most TVEs are high energy consumers. In addition, these bricks are small in size and heavy in weight, and they offer low efficiency in construction; they do not provide good insulation or earthquake resistance. But they are convenient and easy to make: the raw material is available locally, and the production method is simple.28/

64. Energy Intensity. Energy consumption in the brick industry is estimated by Chinese authorities at 49 million tons of standard coal in 1987, of which 96 percent represented coal consumption. The mean energy consumption per unit of production (per million pieces of brick) is estimated at 123 tce. The Chinese building material industry has identified ways to improve brick production or to use alternative materials for the construction industry. The problem is partly one of changing traditional practices and encouraging investments in supplies of new materials.

65. The typical village kiln, of which there are roughly 30,000, produces via a batch process; energy consumption varies but can be as high as 2 tce/10,000 pieces. A more modern kiln (called an "alternate working kiln/tunnel kiln") offers continuous production, and the difference in energy consumption can be as much as 50 percent less. Average energy consumption of continuous kilns is 1.1 tce/10,000 pieces; they represent about one-third of production. The renovation of traditional batch kilns to continuous kilns could save up to 50 percent of the energy used in these kilns.

66. About 10 percent of brick production is done by a method which produces "self-fired" bricks--the heat is generated in the interior of the brick by using boiler ash and washery waste containing unburned carbon. This technique facilitates the use of waste products and conserves carbon. Both continuous kilns and self-fired bricks are being actively promoted in various areas.

28/ Although there are problems with the disturbance to farmlands.

67. Strategy for Better Conservation. The announced strategy for making improvements in this industry is sound. The goal is, first, to renovate existing traditional kilns from batch to continuous process, as far as possible. Remaining local kilns are to be gradually phased out. Second, introduction of modern processes for new kilns is being promoted. Third, more attention is to be given to use of waste products--coal refuse from mines and washery plants, bottom ash and slag from boilers, ash collected in pollution control equipment--to make self-fired bricks. Fourth, new types of bricks, such as "hollow" or aerated bricks, are being introduced; the potential for their introduction are greater among the state-run kilns. Finally, research is continuing in regard to building insulation and new construction materials for housing, reducing the use of brick per m^2 of building area.29/ The results of this research to date indicate there would be material and energy savings by introduction of building insulation.

68. As with many industries cited above, the Chinese authorities already have ideas for change. The problem appears to be developing the incentives to implement change and finding the resources to make investments. Also, technology transfer at the village level, even relatively simple changes of traditional practices, is difficult.

69. Environmental Aspects. The environmental impact of individual brick kilns does not appear to be as big a problem as that of individual cement plants, although this can vary from location to location (depending on where plants are sited and the quality of coal used). More coal is consumed overall in the brick industry; therefore, the cumulative impact of coal burning in kilns may be greater.

70. The larger commercial brick plants tend to have higher stacks, thereby contributing less to ambient particulate concentrations. One operating problem appears to be excessive coal thrown on the grates, with the danger of incomplete combustion and thus loss of carbon. This creates emissions of dark smoke from the kilns. Smaller village kilns do not have high chimneys and are often located very close to where people are living. This could cause local health problems. Better siting of plants would reduce the impact. Greater use of self-fired bricks would also help in this regard.

71. Projections to Year 2000. Based on present construction plans, the estimated demand for bricks in year 2000 will be in the range of 300-480 billion pieces, depending on whether efficiencies in the industry are achieved or substitution of other building materials to reduce demand for bricks. If 480 billion pieces are required, coal consumption (standard coal equivalent) could range from 48-57 million tce, depending on the efficiencies achieved.30/

29/ Refer also to Annex 6.

30/ The assumptions are based on an energy efficiency range of 105 kgce/million pieces to 123 kgce/million pieces, the latter being present energy use rates; coal use is assumed to be 96 percent.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Steam Coal Screening and Washing Analyses 1/

Background on Coal Preparation

1. Coal preparation or beneficiation refers to both screening and washing. Screening is simply the separation of coal by size and the extent of separation depends on the design of the screen. Screening is an essential step in blending coals to match user requirements. It is also done as a first step in coal washing.

2. Coal washing refers to several different methods with differing degrees of fineness and ash reduction. The common technologies, going from coarse to fine cleaning, are: jigging, dense medium bath, dense medium cyclone, and froth flotation. The first three operate on the principle of separation by specific gravity. Froth flotation involves separation via particle surface chemistry. It is for fine coal cleaning and follows a coarse coal cleaning circuit. The design of plants and economics of washing depend on the specific characteristics of the coal feed. Hence, a specific coal analysis must be done in planning a washing investment.

3. Generally, coal over the size range of 4-6 inches x 0 can be washed in jigs with no size separation other than screening out the oversize lumps. A more efficient coal cleaning process might divide the raw coal into coarse and fine fractions with different process equipment for the lump coal (jig) and a froth flotation circuit for the fines (28 mesh x 0). A still more advanced plant could be equipped with three cleaning circuits for different sizes of coal. Fines washing adds about 50 percent to the capital cost of the preparation plant and ultimately increases the generating costs of the recipient utility boiler. But it also reduces ultrafine particulate emissions.

4. Coal washing yields different products, depending on the type of coal. The washing of coking coal results in several products: washed coking coal (about 50-60 percent); "middlings" of about 4,000-4,500 kcal/kg (20 percent); which can be used in power plants; and the remainder, washery refuse, which has still lower calorific and higher ash (it too can be used--in brick-making, for example). Because the requirements for the final product are less stringent, washing of thermal coal produces a higher yield of primary product --generally 80 percent of the yield is thermal coal. The remaining product is washery refuse; middlings are not necessarily produced.

1/ This annex draws from a background report and analyses by D. Symonds.

Table 1: SUMMARY OF CHINESE COAL INDUSTRY SCREENING AND WASHING DATA, 1987

	Mt raw coal	%
Production		
State mines	420	
Local mines	508	
Total	928	100
Coal Screening	192	21
Coal Washing		
State/Provincial Plants		
Total feed to coking coal plants	115	
Total feed to thermal coal plants	48	
Total Feed to State/Provincial Plants	163	17
Small Local Plants /a		
Estimated feed to local coking coal plants	17	
Estimated feed to local thermal coal plants	0	
Total Washed by Local Plants	17	2
Total Washed		
Total feed to all coking coal plants /a	132	
Total feed to all thermal coal plants	48	
Total Washed	180	19

/a Calculated.

Source: Chinese Coal Industry Manual 1987, Tables 10, 11 and 23.

Table 2: COAL SCREENING ANALYSIS

Year	Costs: Production (M tons)	Costs: Coal screening (Y M)/a	Benefits: Carbon saved (M tons)	Benefits: Carbon savings (Y 150/t) /b	Net cash flow
1		9.00	0.00	0.00	(9.00)
2		15.00	0.00	0.00	(15.00)
3	2.10	3.15	0.05	7.88	4.73
4	2.70	4.05	0.07	10.13	6.08
5	3.00	4.50	0.08	11.25	6.75
6	3.00	4.50	0.08	11.25	6.75
7	3.00	4.50	0.08	11.25	6.75
8	3.00	4.50	0.08	11.25	6.75
9	3.00	4.50	0.08	11.25	6.75
10	3.00	4.50	0.08	11.25	6.75
11	3.00	4.50	0.08	11.25	6.75
12	3.00	4.50	0.08	11.25	6.75
13	3.00	4.50	0.08	11.25	6.75
14	3.00	4.50	0.08	11.25	6.75
15	3.00	4.50	0.08	11.25	6.75
16	3.00	4.50	0.08	11.25	6.75
17	3.00	4.50	0.08	11.25	6.75
IRR (%)					22.9%
NPV 10%		47.5		67.4	19.9
15%		37.9		46.9	9.0

/a Based on an investment cost of Y 8/ton and operating costs of Y 1.5/ton.

/b Assume carbon savings are 2.5 percent of total production or about 4 percent of the total carbon content.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Assumptions for Washing Analysis

Objective: Comparison of cost of transporting raw and washed coal to provide same calorific value per annum

1. Transport

Shipping distance:	1,800 km	
Unit shipping cost:	Y 0.034/tkm	
Shortage cost:	Y 0.072/tkm	
Calculation of shortage cost:	Free market price, Shanghai:	Y 250/t
	Free market price, Shanxi:	Y 120/t
	Difference:	Y 130/t

Result: Y 130/t divided by 1,800 km = Y 0.072/tkm

Note: This shortage cost actually reflects the combination of distance transported and the higher end value in the final market; this shortage value varies, depending on the distance and free market price in the final market.

2. Mining cost

Capital cost:	Y 260/ton
Operating cost:	Y 40/ton

3. Washing cost

Capital cost:	Y 30/ton
Operating cost:	Y 3.0/ton /a

4. Production data	Raw coal	Clean coal	Refuse
Tons raw coal produced (@ 6% moisture)	3,000,000	3,250,000	-
Clean coal results	-	2,600,000	650,000/b
Ash (% db)	25	15	65
% of Wt.	100	80	20
kcal/kg	5,903	6,809	2,281
Total moisture (%)	6	7	
Ash (% ar)	23.5	13.95	
kcal/kg (ar)	5,547	6,332	
MJ/kg	23.2	26.5	
Tons delivered	3,000,000	2,628,000	
Total kcal delivered	16,641,000	16,641,000	

/a Excluding Y 5/ton for handling facilities included in mining cost.
/b At mine site.

Objective: Analysis of emissions: raw vs. washed coal

Coal quality:

ROM ash content:	25%
ROM sulfur content:	1.2%

1. Coal Going to Industrial boiler:

Emission rate:	35% of ash 95% of sulfur
Ash collection rate:	60-70%
Ash reduction:	45%
Sulfur reduction:	25%
Ash disposal savings:	Y 2.00/ton coal arr.
Maintenance savings:	Y 3.00/ton coal arr.

2. Coal Going to Electric Power Boiler:

Emission rate:	85% of ash 95% of sulfur
Ash collection rate:	85%
Ash reduction:	24%
Sulfur reduction:	25%
Ash disposal savings:	Y 1.50/ton coal arr.
Maintenance savings:	Y 4.50/ton coal arr.
Increased boiler availability:	2% increase in availability at about seven 100 MW plants (taking 315,000 tpa of coal each). Additional electricity is valued at a shortage cost of Y 0.5/kWh

Table 3

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Raw Coal vs. Washed Coal Costs

(Distance: 1800 km; 25% ash)
(million yuan)

Raw Coal

Year	Total kcal (M kcal)	Annual product. (M ton)	Costs: Mining Capital	Mining Operat.	Washing Capital	Washing Operat.	Transp. (.072Y/tkm)	Total
1			39.37					39.37
2			118.10					118.10
3			157.46					157.46
4			196.70					196.70
5			157.46					157.46
6	3.33	0.60	78.73	24.56	0.00	0.00	73.44	177.33
7	8.32	1.50	39.37	61.32	0.00	0.00	183.60	285.79
8	11.65	2.10	15.72	85.98	0.00	0.00	257.04	358.74
9	14.98	2.70	15.72	110.48	0.00	0.00	330.48	459.33
10	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
11	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
12	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
13	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
14	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
15	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
16	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
17	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
18	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
19	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
20	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
21	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
22	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
23	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
24	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
25	16.64	3.00	15.72	122.78	0.00	0.00	367.20	505.70
NPV = 10%	73.15	13.2	614.6	539.6	0.0	0.0	1,614.1	2,781.5

AIC = 87.53 yuan/ton FOB mine; 210.93 yuan/ton arr.
15.78 yuan/M kcal FOB; 38.03 yuan/M kcal arr.

Washed Coal

Year	Annual product. (M ton)	Costs: Mining Capital	Mining Operat.	Washing Capital	Washing Operat.	Transp. (.072Y/tkm)	Total
1		42.61		0.00			42.61
2		127.84		0.00			127.84
3		170.59		13.00			183.59
4		213.20		19.00			232.20
5		170.59		30.90			201.49
6	0.53	85.28	26.63	30.00	1.69	64.87	208.42
7	1.31	42.61	66.52	4.00	4.29	160.34	278.36
8	1.84	17.02	93.15	0.00	5.98	225.22	341.37
9	2.37	17.02	119.66	0.00	7.67	290.09	434.44
10	2.63	17.02	133.04	0.00	8.58	321.91	480.55
11	2.63	17.02	133.04	0.00	8.58	321.91	480.55
12	2.63	17.02	133.04	0.00	8.58	321.91	480.55
13	2.63	17.02	133.04	0.00	8.58	321.91	480.55
14	2.63	17.02	133.04	0.00	8.58	321.91	480.55
15	2.63	17.02	133.04	0.00	8.58	321.91	480.55
16	2.63	17.02	133.04	0.00	8.58	321.91	480.55
17	2.63	17.02	133.04	0.00	8.58	321.91	480.55
18	2.63	17.02	133.04	0.00	8.58	321.91	480.55
19	2.63	17.02	133.04	0.00	8.58	321.91	480.55
20	2.63	17.02	133.04	0.00	8.58	321.91	480.55
21	2.63	17.02	133.04	0.00	8.58	321.91	480.55
22	2.63	17.02	133.04	0.00	8.58	321.91	480.55
23	2.63	17.02	133.04	0.00	8.58	321.91	480.55
24	2.63	17.02	133.04	0.00	8.58	321.91	480.55
25	2.63	17.02	133.04	0.00	8.58	321.91	480.55
NPV = 10%	11.6	685.7	594.8	61.2	37.7	1,415.1	2,794.5

AIC = 116.72 yuan/ton FOB mine; 239.12 yuan/ton arr.
18.45 yuan/M kcal FOB; 37.79 yuan/M kcal arr.

Table 4

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Industrial/Heating Boilers

(in million yuan; 25% ash)

Year	Production (M ton)	Costs: Coal washing	Costs: Mining cost /_1 diff.	Costs: Total	Benefits: Transp. cost savings	Benefits: Less ash disposal (2.0Y/t)	Benefits: Less maint. (3.00Y/t	Benefits: Boiler availab. 0.00	Benefits: Total	Net cash flow (with transp.)	Net cash flow (w/out transp.)	Emission Reductions ('000 t): TSP /_2 (Range depends on control equipment)		Emission Reductions ('000 t): SO2 /_3 (25%)
1		0.00	3.24	3.24						(3.24)	(3.24)			
2		0.00	9.74	9.74						(9.74)	(9.74)			
3		13.00	13.13	26.13						(26.13)	(26.13)			
4		19.00	16.50	35.50						(35.50)	(35.50)			
5		30.90	13.13	44.03						(44.03)	(44.03)			
6	0.53	31.69	8.57	40.26	8.57	1.06	1.59	0.00	11.22	(29.04)	(37.61)	3.54	7.09	3.10
7	1.31	8.89	8.44	17.33	23.26	2.62	3.93	0.00	29.81	12.48	(10.78)	8.76	17.51	7.66
8	1.84	5.98	8.57	14.55	31.82	3.68	5.52	0.00	41.02	26.47	(5.35)	12.30	24.60	10.76
9	2.37	7.67	10.53	18.20	40.39	4.74	7.11	0.00	52.24	34.04	(6.35)	15.84	31.69	13.86
10	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
11	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
12	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
13	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
14	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
15	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
16	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
17	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
18	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
19	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
20	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
21	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
22	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
23	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
24	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
25	2.63	8.58	11.56	20.14	45.29	5.26	7.89	0.00	58.44	38.30	(6.99)	17.58	35.16	15.39
									IRR =	15.9%	--			
NPV	10%	98.9	96.3	195.2	199.0	23.1	34.7	0.0	256.8	61.7	(137.4)			

/_1: "Mining cost differential" = Additional mining costs due to additional feed coal needed in washing.
/_2: Removal rate of pollution control equipment assumed in the range of 60-80%.
/_3: Assumes 1.2% sulfur in coal and 25% removal rate.

Table 5
EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Electric Power/Industry Boilers Analysis

(in million yuan; 25% ash)

		Total Costs			Benefits: Industry (27%)				Benefits: Electic power (73%)					Net cash flow		Emission Reductions	
Year	Production (M ton)	Coal washing costs	Mining cost difference	Total	Transp. cost savings	Less ash disposal (2.0Y/t)	Less maint. (3.00Y/t	Total	Transp. Cost savings	Less ash disposal (1.5Y/t)	Less maint. (4.5Y/t)	Incr. Boiler Availability (2%) /1	Total	(with transp.)	(w/out transp.)	TSP /2	SO2 /3
1		0.00	3.24	3.24								0.00		(3.24)	(3.24)		
2		0.00	9.74	9.74								0.00		(9.74)	(9.74)		
3		13.00	13.13	26.13								0.00		(26.13)	(26.13)		
4		19.00	16.50	35.50								0.00		(35.50)	(35.50)		
5		30.90	13.13	44.03								0.00		(44.03)	(44.03)		
6	0.53	31.69	8.57	40.26	2.31	0.37	0.43	3.11	6.26	0.50	1.74	6.75	15.25	(21.90)	(30.47)	4.67	3.10
7	1.31	8.89	8.44	17.33	6.28	0.92	1.06	8.26	16.98	1.22	4.30	16.70	39.20	30.13	6.87	11.55	7.66
8	1.84	5.98	8.57	14.55	8.59	1.29	1.49	11.37	23.23	1.71	6.04	23.45	54.44	51.26	19.44	16.23	10.76
9	2.37	7.67	10.53	18.20	10.91	1.66	1.92	14.49	29.48	2.21	7.79	30.21	69.69	65.98	25.59	20.90	13.86
10	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	33.52	77.67	73.74	28.45	23.19	15.39
11	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	33.52	77.67	73.74	28.45	23.19	15.39
12	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	33.52	77.67	73.74	28.45	23.19	15.39
13	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	33.52	77.67	73.74	28.45	23.19	15.39
14	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	33.52	77.67	73.74	28.45	23.19	15.39
15	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	33.52	77.67	73.74	28.45	23.19	15.39
16	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	13.41	57.56	53.63	8.34	23.19	15.39
17	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	13.41	57.56	53.63	8.34	23.19	15.39
18	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	13.41	57.56	53.63	8.34	23.19	15.39
19	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	13.41	57.56	53.63	8.34	23.19	15.39
20	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	13.41	57.56	53.63	8.34	23.19	15.39
21	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	13.41	57.56	53.63	8.34	23.19	15.39
22	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	13.41	57.56	53.63	8.34	23.19	15.39
23	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	13.41	57.56	53.63	8.34	23.19	15.39
24	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	13.41	57.56	53.63	8.34	23.19	15.39
25	2.63	8.58	11.56	20.14	12.23	1.85	2.13	16.21	33.06	2.45	8.64	13.41	57.56	53.63	8.34	23.19	15.39
													IRR =	25.8%	8.4%		
NPV	10%	98.9	96.3	195.2	53.7	8.1	9.4	71.2	145.3	10.8	38.0	117.8	311.8	187.9	(11.1)		

/1: Assumes 2% increase in availability for about seven 100 MW plants

/2: Assumes 35% of ash is captured in the flue gas of industrial boilers and 85% in utility boilers.

/3: Assumes 1.2% sulfur in the coal, 95% of which is released as SO_2 and a 25% removal rate from washing.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Washing of Coking Coal 1/

A. Background on Washing of Coking Coal

1. The bulk of washed coal in China is coking coal. Steel making technology dictates that the ash content of coking coal be as low as possible, preferably 6 to 9 percent, although financial considerations may limit washing to 11-12 percent ash (this occurs in China). Since it is almost impossible to produce bulk raw coal with modern mining methods at such a low ash level, it is necessary to wash the coal before it can be fed to coke ovens.

2. Total coking coal washed in 1987 was approximately 132 million tons. The quantity washed in state-owned or the larger provincial and county plants (with capacities greater than 0.5 million tpa) was 115 million tons in 1987. This indicates that 17 million tons were washed in smaller local plants.2/ Of total feed, 53 percent is shipped to metallurgical markets, 19 percent represents middlings and related products going to thermal markets (e.g., utility and FBC boilers), and 28 percent is either discarded or sold to brick making facilities, if available in the local area. In many cases, the middlings generated from coking coal washing in Shanxi are shipped in excess of 600 km to other markets, which would appear to be uneconomic on a calorific value basis. Where possible, it would be best to use middlings for power generation in Shanxi.

B. Plant Size in China

3. Metallurgical coal preparation plants in China can be divided into three categories:

(a) very large and complex plants with annual capacities greater than 1.0 million tpa;

(b) medium sized plants with capacities between 0.3 and 1.0 million tpa; and

(c) small, local plants with capacities below 0.3 million tpa.

Large Complex Plants

4. These plants are large by world standards and probably account for over 80 percent of the coal washed in China. They invariably serve a single

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1/ This annex draws from a background report by D. Symonds. It also benefited from the data and analyses of Working Paper No. 4 by the China General Coal Utilization and Development Corporation.

2/ There appear to be a significant number of local preparation plants with individual capacities of less than 300,000 tpa which may not be reflected in these figures, however.

large underground mine. Four important factors affect the economics of these plants. First, they tend to share a common appearance and design philosophy--with large plant areas, complicated process configurations and redundancy of equipment. Many of the plants have very similar overall flowsheets. There are advantages to be gained from this practice in terms of operator familiarity and training, standardization of spare parts, etc. But each washing investment must be examined individually, taking into account the economic factors associated with the specific properties and washability of the feed coal and the unique transportation or marketing requirements. Such an approach would lead to design of more efficient, cost effective and diverse plants.

5. Second, the plants take a very long time to reach design capacity. It is quite common for the plants to take five to six years to construct and then an additional two to three years to reach design capacity. This construction and commissioning period is two to three times longer than the customary time in industrialized nations. Third, utilization of major equipment is low. The plants tend to be equipment intensive, whereas the coal storage and handling facilities (which provide a plant with greater operating flexibility) are very basic. Both domestically manufactured and imported equipment are used. There is an abundance of stand-by equipment which appears to be utilized infrequently. It is recognized that spare parts are often difficult to obtain, but the accepted procedure of substituting spare equipment for spare parts appears excessive.

6. Finally, the capital plant cost per annual ton of throughput is high. This is mainly due to the equipment excesses described above. An adjunct to this is the very low borrowing charges levied upon the mine by the central government. In most cases, these charges are minimal (0.24 percent annual interest charge) and are often directly related to the mine's apparent profitability. If the preparation plant is not profitable, then the loan payments are reduced or postponed. The result is that the mine is not penalized, to the appropriate degree, for having a very large and expensive facility which may only be operating at 50 percent of capacity. Thus, an inherent incentive to reduce the initial capital cost and/or maximize plant throughput is substantially diminished.

Washeries Servicing Local Mines

7. Individual mines producing less than 100,000 tpa often are unable to secure funds or justify the necessary capital expenditure to wash coal. Clearly, there is no incentive if they must sell their coal at allocated prices. Lack of access to transport also sometimes means that these smaller plants cannot sell their coking coal (even if it were washed) at the higher negotiated price. The result is that prime coking coal is being sold in some areas as a raw thermal fuel. The solution is to wash the coal at centralized washing plants.

8. Small-Sized Plants. A number of small to very small plants (5,000 to 300,000 tpa) have developed in some of the coal mining areas. In areas like southern Shanxi, they produce washed coking coal with 8 to 10 percent ash (this is excellent quality coal). They are owned by counties and cities, and some are privately held. The raw coal feeding these plants is received from

multiple small mines in the neighboring area and is crushed to pass a 10 mm screen. The washed coal is sluiced out to settling ponds where it is allowed to drain. It is then manually dug up and transported to adjacent beehive ovens for coke making. Plant water clarity is very poor, and much of the original water is allowed to be discharged into the countryside. These plants use excessive quantities of water per ton of throughput. In terms of technology, they represent coal preparation in its most elementary form--technology that is more than half a century old.

9. A typical plant capable of processing 90,000 tpa costs about Y 1 million (1985 data), which equates to less than Y 20/ton of annual capacity (including the preparation plant and the coke making facility). It is apparent from the proliferation of new installations that these coal washing and coke making facilities are extremely profitable. Regrettably, they are significant sources of atmospheric and waterborne pollution. Furthermore, these plants are losing possibly 10 to 20 percent of the available coking coal as a result of inefficient washing methods. These yield losses are excessive. These plants need better jig or other coarse coal cleaning devices. They also require a fine coal cleaning and dewatering system. It is important that the fine coal be recovered for both economic and environmental reasons. The cost of prime grade coking coal on the free market is very high.

The Need for Medium-Sized Plants

10. Experience in the industrialized world proves that small plants do not have to be inefficient, and closed water circuits can operate equally well at 50 tpa or 2,000 tpa. However, the size of major units--such as jigs, dense medium vessels, thickeners, filters, etc.--generally dictate that the lowest practical annual throughput for a preparation plant is 200,000 tons. Such plants can be as efficient and environmentally safe as a much larger plant processing 4 million tpa.

11. There appear to be very few of these medium-sized plants in existence in China, whereas they probably account for over 50 percent of the washing capacity in industrialized nations. The basic design and level of sophistication are similar to the larger plants described above at (i). Capital costs are similar to, if not slightly lower than, those of the large plants Y 35 to 45/ton of annual capacity). The rate of construction and capacity utilization are likely to be much better, however.3/

C. Technology

12. China currently possesses all of the significant new technology in coal preparation. But considerable improvements in coal washing efficiency

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3/ A good example of a recently built plant of this type is the Guzhou City plant in Shanxi Province. This is a dense medium cyclone plant with an annual capacity of 300,000 tpa. It was constructed and put into operation in less than one year at a cost of Y 18/annual ton. The plant does require additional equipment to close the water circuit completely, but this could be accomplished for less than 30 percent of the original cost.

and usage can be achieved by applying existing technology in more productive ways.

Jigs versus Dense Medium Systems

13. The predominant technology used in beneficiating metallurgical coals in China is jigging. Some of the more recent plants contain dense medium circuits, but these are the exception rather than the rule. The ratio of dense medium-based systems to jigs for metallurgical plants in the industrialized nations is close to 4 to 1, whereas this ratio appears to be reversed in China. Dense medium plants offer two major advantages:

(a) they can perform separations at lower gravities than jigs. This results in lower clean coal ash content (less than 9 percent);

(b) they are more efficient than jigs; thus, less "saleable" coal is lost to middlings or rejects.

14. It would appear that dense medium systems have been underutilized in China because of the more complex technology and higher initial capital cost. In general, dense medium systems (both bath and cyclones) would add approximately 5-10 percent to the capital cost of a plant. Operating costs may also be higher by a similar percentage. These costs are usually justified, however, in terms of enhanced clean coal recovery. Observations and conversations with operating personnel suggest that the technological barrier is being overcome with day to day operating experience. In fact, many of the dense medium circuits visited during the study were operating satisfactorily. The capital cost is being mitigated with introduction of domestic dense medium equipment.

15. The move towards greater use of dense medium systems in metallurgical coal preparation plants should be encouraged since it will result in a more efficient utilization. The additional clean coal yield from a dense medium system (versus a jig) can be as high as 5 percent of the raw coal feed. When site-specific comparisons of jigging versus dense medium cleaning for metallurgical coals are conducted in industrialized countries, the long term preferred option is the latter system due to the increased yield of clean coal. Moreover, when dense medium processes are used in China they invariably are dense medium vessels (baths). Greater use should be made of dense medium cyclone systems which can beneficiate coal with a mean particle diameter as low as 0.5 mm.

Thermal Dryers

16. Thermal dryers are not widely used, even though the total moisture content of the coking coal is high and transportation distances are long. Coking coals in North America are generally dried to below 8 percent total moisture. The merit of accepting 2 to 3 percent additional moisture in undried coking coal must be assessed from both economic and technical perspectives. In economic terms, there is a trade-off between the costs associated with thermally drying the coal and the reduced transportation cost associated with shipping dryer coal. A typical fluidized bed thermal dryer, with the appropriate ancillary equipment for a metallurgical coal preparation circuit,

costs about 25 percent of the total plant cost. The technical problem with higher surface moisture coal is its tendency to freeze in winter; this is a particular problem for coking coal. It can cause severe problems at the point of consumption when the frozen coal cannot be removed from the rail cars. Press reports indicate this has been a problem in transporting coal from Shanxi to steel plants in East China (Shanghai). Such problems have been a factor in the decision to import some coking coal into East China during winter.

17. In regard to technology adaptation, there are very few large capacity (fluid-bed type) thermal dryers in operation in China. Those that are in place appear to have operational problems relating to dust emissions and over-drying. These problems need to be addressed.

D. Plant Costs

18. Coking coal plants tend to be more costly to build compared with thermal coal washing plants because:

(a) they have to be more efficient, due to more stringent (lower) ash specifications;

(b) for the above reason and also higher prices, the fines have to be washed and dewatered;

(c) thermal dryers are often used.

19. The average 1989 capital cost of washing is estimated at Y 35 per ton of annual capacity. The capital cost consists of two components: the coal preparation plant and the coal storage and handling facilities. The coal storage and handling facilities in China tend to be smaller and less elaborate than their western counterparts. In the West, the capital investment allocation would be 50 percent to coal handling and storage and 50 percent to the preparation plant. For Chinese facilities, the corresponding split is estimated to be 33 percent to coal handling and storage and 57 percent to the coal preparation plant. The mean operating cost is estimated at Y 4.0/t raw coal. The breakdown between coal handling and coal preparation would be approximately Y 1.25/t for handling and Y 2.75/t for preparation.

E. Investment in Future Capacity

Better Utilization of Existing Plants

20. An appraisal of the potential of retrofitting preparation plants should be preceded by an examination of the utilization of existing plants. Of 12 plants visited for this study, the combined design throughput capacity was 20 million tpa. The actual throughput tonnage for 1988 was 11 million tons, however. This equates to a utilization factor of 55 percent. It is recognized that this factor is depressed as a result of a number of new plants which are slowly building up capacity (start-up phase). However, this factor is extremely low, particularly when demand for coking coal is so strong. The elements which contribute to this poor utilization are:

(a) an extremely long period (up to five years) between plant commissioning and attainment of full design capacity;

(b) lack of adequate raw and clean coal storage and handling capacity at the mine which results in preparation plant shut downs, due to either insufficient coal from the mine or lack of trains to transport the clean coal.

(c) lack of long term coordination and planning within a coalfield or lack of flexibility which would permit excess coal production from one mine to be shipped to an underutilized preparation plant.

Additional coal handling and storage facilities at the mines would enable new mines to achieve a much higher utilization level, since stoppages due to lack of raw coal or trains could be significantly reduced. The possibility also exists of increasing throughput substantially by simply improving designs levels and making maximum use of each item of equipment.

Retrofitting and Expansion of Existing Plants

21. The preparation plants in China tend to be very spacious in relation to their capacity. As a result the equipment within the plant is not congested and there is ample room for additional equipment. Furthermore, most of the plants visited contained additional standby equipment. It was quite common to see plants operating at full design capacity but utilizing only 60 percent of the major mechanical equipment.

22. It is difficult to state categorically that retrofitting would offer major advantages in terms of increased preparation plant capacity, since each situation must be site specific. However, the general impression created during site visits for this study was that retrofitting would not only be technically successful, but also extremely attractive from an economic viewpoint. This alternative for increasing washing capacity should be pursued as a first priority. The data collected during the site visits indicated that the cost of retrofitting would be about Y 20-30/annual ton, compared with Y 53/annual ton for a new plant. Small increases in capacity (up to 20 percent) could probably be achieved for approximately Y 20/annual ton. It would represent a savings of Y 150 million in current values.

Design of Medium Size, Centralized Plants

23. As discussed earlier, the majority of raw coal tonnage washed is directed through plants whose capacities are in excess of 1 million tpa. These plants invariably serve a single large underground mine. At the other end of the spectrum are a large number of small inefficient plants (less than 100,000 tpa) which use outmoded technology and are generators of waterborne pollution. Since a substantial amount of future coking coal production expansion in China will take place in local mines, there is a strong need for more preparation plants whose capacities are between 100,000 tpa and 500,000 tpa. These medium size, centralized plants offer the following advantages:

(a) low capital cost per ton of throughput (Y 25 to Y 35/t annual capacity);

(b) shorter time for construction and commissioning (24 months versus 60 months);

(c) less demands on resources of all types (human, infrastructure, etc.) in remote mining areas.

On the negative side these plants generally have higher operating costs. However, the advantages mentioned above should outweigh this disadvantage.

F. Investments in Washing Capacity to Year 2000

24. The estimate of additional capital requirements for metallurgical coal preparation through the year 2000 is presented in Attachment 1. An attempt has been made to identify the various methods of achieving additional throughput by better utilizing and modifying existing plants as well as building new plants. The most cost effective method of increasing capacity would be to modify and expand as many existing plants as possible. In the example in the table, it is estimated that 48 percent of the new capacity required could be met by (i) utilizing existing unused capacity (at minimal cost of Y 5/ton) and (ii) retrofitting existing plants (cost estimated at Y 30/annual ton). The total cost of achieving an increase in coking coal washing capacity of 123 million tpa by the year 2000 is estimated Y 4.1 billion.4/ This compares with Y 6.5 billion for the construction of large, new preparation plants (at Y 53/annual ton), without modifying existing plants. This represents a savings of almost 40 percent.

4/ Before price contingencies.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Investment in Washing Capacity - Metallurgical Coals

		Million tons		
A. Existing (1987) annual tons washed (raw coking coal)	=	132		
B. Future annual raw tons to be washed (2000)	=	255		
Future washing requirement	=	123		
Existing unused capacity @ 25% of A	=	33		
Retrofit capabilities for existing plants @ 20% of A	=	26		
New plant capacity required	=	64		
New capacity from small (<500,000 tpa) plants	=	23	18.7%	
New capacity from large (500,000 tpa) plants	=	100	81.3%	
			Capital cost	
Total Capital Requirements			Y/ton	Y M
Existing unused capacity @ 25% of A	=	33	5	165
Retrofit capabilities for existing plants @ 20% of A	=	26	30	780
Additional new small plants capacity required	=	12	30	360
Additional new large plants capacity required	=	52	53	2,756
Total	=	123		4,061

Note: Cost of increasing existing capacities is estimated at Y 5/annual tons due to costs associated with minor plant adjustments and costs of modifying coal reception areas.

CHINA

EFFICIENCY AND ENVIRONMENTAL IMPACT OF COAL USE

Advanced Coal-Based Technologies: FBC and CWS 1/

1. Two technologies are discussed here because of strong interest in them among many Chinese authorities and their potential use in industry and other applications over the longer term. They are fluidized bed combustion and coal water slurry.

A. Role of FBC Technology

2. There is strong interest in fluidized bed combustion among Chinese authorities because of its greater fuel flexibility (although that must be designed in the unit at additional cost). FBC units can burn low quality fuels (1,000-2,500 kcal/kg), high in moisture and ash; also, moderate reductions in sulfur are obtained via limestone injection. The application of fluidized bed combustion technology (FBC) to provide greater coal quality flexibility in coal-fired boilers began in the UK and China about the same time, in the early 1960s.2/ Growing environmental concerns and stricter regulations (concerning sulfur control particularly) spurred research and development in OECD countries in the late 1960s and 1970s for larger scale applications.

3. In the United States, the most frequent use of FBC is for industrial cogeneration.3/ Larger units are now being introduced and operating problems being worked out. It is expected that FBC boilers will be used commercially in large scale power generation in the mid-1990s. Its attraction is to provide an alternative to flue gas desulfurization (FGD), although developments in FGD continue to make it a strong, competitive technology for sulfur control also. This is discussed in Chapter VI.

4. The experience with FBC in the West indicates the need for realistic tests on specific coals and limestone before designs are fixed. Interdisciplinary approaches to technology development are needed because FBC relies on both mechanical and chemical processes.

1/ This section is based on analyses and information from D. Simbeck, SFA Pacific Inc., June 1989.

2/ FBC technology dates back to the 1920s, but its development and use in various applications accelerated after World War II.

3/ The trend now is away from small bubbling FBC units with minimal emission control to larger circulating FBC with moderate emission reduction. Until 1985, most installed FBC boilers were relatively small bubbling bed units. The commercialization of circulating FBC began in the 1980s and has proved a competitive technology.

5. At present, there are about 3,000 FBC units operating in industry in China, producing a total of 20,000 steam tons per hour, which represents less than 5 percent of total industrial steam production. For small scale electric power, FBC represents a very small percentage of generating capacity--about 330 MW. Essentially, all commercially operating FBC boilers in China are small overbed feed, bubbling FBC units (typical size being 1.5 stph). This type of FBC boiler has a simple design and is inexpensive to build. In remote locations, FBC boilers burn mine waste and the rejects from washing.4/ In fact, most FBC operating in China today are located in mining areas. This is a very practical niche for FBC.

6. Unfortunately, insufficient attention has been given to emission controls on these boilers. Very little limestone injection is undertaken for sulfur removal, and in many cases even adequate fly ash collection equipment is not employed. Fly ash emissions can be especially high with FBC because of the poor quality coal used as feed; therefore, FBC boilers should be equipped with high efficiency dust collectors. There seems to be an inability to act on available knowledge and technology to improve the less than optimum performance of existing bubbling bed FBC.5/

7. In China, important research is being conducted on the two major types of FBC--bubbling and circulating FBC--at various institutions, including the Chinese Academy of Science, Qinghua University, and several research institutes under the Ministry of Machinery and Electronics Industry. In the immediate future, China should continue to concentrate on development of FBC for utilization of low quality fuels, such as washery waste and lignite. For some years to come, most of the FBC boilers produced in China will be the bubbling bed type, and resources are needed to upgrade their performance. Attention should also go to development of industrial size circulating FBC (CFBC) for use of high ash bituminous coals or washery waste. A future potential application for FBC in China may be in industrial heat production in densely populated industrial centers as a means to control some SO_x. For efficient fuel use in such circumstances, circulating FBC is being favored in Western countries. CFBC units also more effectively handle fines. On the other hand, they are more expensive.

8. A concern that is developing with regard to FBC is the extent of waste disposal and its costs. FBC, while reducing SO_x, increases the waste material from the boiler in a form which does not make it readily usable. Solid waste generated by FBC has been identified by industry analysts as a major problem for the technology, still to be resolved. For future technology development in China, emphasis should be on adaptation of existing technology, through licensing or joint ventures with a variety of international vendors to benefit from their experience--and the problems encountered--in

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4/ Mine and washery refuse contains significant amounts of carbonaceous material, often enough to be a fuel for FBC.

5/ The Shanghai Power Equipment Research Institute has designed and developed a shop-fabricated (packaged) industrial FBC boiler which apparently incorporates the technology needed for efficient coal use and environmental control. But the problem appears to be promotion of its use and lack of acceptance because of a higher price.

commercializing and scaling up the technology and to seek exposure to different forms of the technology. In this way, Chinese engineers can adapt those elements of FBC technology which most suit domestic needs.

9. Finally, while there is a future role for FBC, it is important to keep its potential in perspective. Its impact in the medium term will be much less important than that of supplying screened and clean coal to industrial and utility boilers and assuring better design, manufacture and operation of those boilers.

B. Coal Water Slurry

10. China is trying to reduce the use of oil in boilers and improve coal transportation. Coal water slurry technology (CWS) represents one alternative. The use of CWS in oil-designed boilers was a subject of great interest in industrialized countries just after the 1979 oil price shock. But generally very few boilers were converted to CWS because of the large derating (20-50 percent) of boilers designed for oil, the high investment cost, and environmental concerns. The derating is due to the ash content of coal (and its effect on the heat transfer equipment) and to the flue gas velocity limitation in the boiler's convection section, interfering with complete combustion.

11. The cost of CWS is significantly higher than conventional steam coal due to extensive coal washing and expensive chemical additives to stabilize the slurry. As a general "rule of thumb", the cost of CWS would be about 75-100 yuan per metric ton dry coal plus the feed coal cost. The conversion of a boiler from oil to coal would also increase the uncontrolled particulate emissions by a factor of over 100. Therefore, particulate control investments would be required. SO_2 and NO_x could increase or decrease depending on the sulfur and nitrogen contents of both fuels.

12. CWS pipelines require lower capital and are faster to build than new railroads, but they carry only coal slurry; hence, they are not as flexible and cannot facilitate other economic activities as railways do. Given the extent of dedicated rail capacity for coal, the significance of such flexibility may not be great, however. CWS pipelines are also likely to require imported equipment, such as large slurry pumps. Imported equipment is probably the reason why proposed CWS pipeline projects in China usually call for some of the slurry to be exported. It is questionable, though, whether CWS can be effectively marketed abroad relative to conventional steam coals.

13. The Chinese authorities are currently building a CWS demonstration facility at an existing coal washing plant in Shandong province. CWS will be transported by rail tanker cars and burned in three 50 MW oil-designed power plants. Several large scale projects are also proposed and are in various stages of being evaluated. Most involve slurry preparation at mine/coal cleaning plants in Shanxi or Shaanxi provinces for transport by pipelines running east to the coast. Some of the coal would be utilized on the way for conversion of existing oil or new CWS utility power plants; it is planned that a portion would be exported. Such high slurry concentration long distance pipelines are likely to have very high costs associated with pumps and power consumption due to the high pressure drop per km. Recent feasibility studies

indicate satisfactory returns are possible in cases where large volumes of CWS (5 million tons) are supplied to dedicated coal-fired utility boilers. The economics must be carefully considered for a particular route and end use, however.

14. While reservations remain regarding CWS, continuing research and development should be encouraged because of the uncertainty over future oil prices and the fact that CWS could be attractive under specific circumstances. CWS could be produced as a by-product at large coal cleaning plants based on dense medium separation. Such plants might produce a small quantity of very low ash premium CWS (5-10 percent of the total coal), while producing mostly normal ash coal. Low ash content at a reasonable cost is the key to CWS conversion of existing domestic oil fired boilers.