A Study of Biomass as a Source of Energy in China

Jiao Qingyu and He Yuan-bin
Liaoning Institute of Energy Resources
CHINA

S.C. Bhattacharya, Mahen Sharma, and Ghulam Qambar Amur
Energy Program
School of Environment, Resources and Development
Asian Institute of Technology
P.O. Box 4, Klong Luang, Pathumthani 12120
THAILAND

ABSTRACT

In China, the biomass energy consumption during the year 1993 is estimated as about 185 million tons oil equivalent (MTOE). The shares of agricultural residues, fuelwood and animal wastes in the total biomass use for energy were 57.5%, 39.2% and 3.2%, respectively. Annually about 213 MTOE of agricultural residues and about 200 billion kg of dry animal wastes could be potentially available as energy source. Most of the biomass energy (about 89% of the total) is consumed by cookstoves. The household sector alone accounts for about 94% of the total biomass energy consumption in the country. It has been projected that the fuelwood demand will reach about 89 MTOE in the year 2010, implying that fuelwood will remain an important source of energy in China in the foreseeable future.

1. INTRODUCTION

Coal, crude oil, hydropower and natural gas are the main conventional energy sources used in China. It is reported that about 962 MTOE of energy was used in 1993 in China [1], out of which, about 19% came from biomass [2, 3], while the rest was supplied by the conventional sources such as coal, crude oil, hydropower and natural gas.

Table 1 shows the population and total energy usage in China in 1994 and the projections for the year 2010. The population has been projected to approach 1.39 billion in 2010. Fuelwood consumption is expected to increase from about 77 MTOE in 1994 to about 89 MTOE in the year 2010, whereas, the consumption of conventional fuels is projected to increase from about 782 MTOE in 1994 to about 1705 MTOE by the year 2010.

The amount of energy consumed in rural area accounts for a large fraction of the total national energy consumption in China. It has been reported that the energy used in rural areas accounts for virtually all of the country's biomass energy use and about 28% of its conventional energy use [4]. Also, out of the total energy consumption of about 399 TOE in rural areas in 1992, the shares of energy from fuel wood and agricultural residues were about 19.4% and 23.8% respectively [5]. Thus, it can

Table 1. Population and energy usage in China in 1994 and projection for 2010.

	Year	1994		2010	
	Population[1]	1.22 billion[a]		1.39 billion	
Fuel	Units	billion kg per year	MTOE per year	billion kg per year	MTOE per year
Fuelwood	Potential supply[2]	599	211	640	226
	Estimated consumption[3]	219	77	253	89
Agricultural residues	Potential supply[4]	962	338	1330	451
	Estimated consumption[5]	-	96	-	-
Conventional fuels[6]	Coal		569		1200
	Oil		153		334
	Gas		16		84
	Electricity		44		87
	Total		782		1705

[a] 1995 estimates

[1] [6], [2, 3, 4, 5] [7], [6] [1] for 1993 consumption and [8] for 2010.

be seen that biomass plays a vital role in meeting the national energy demand in China. However, reliable estimates of biomass energy consumption for different end uses is normally not available. This paper tries to assess details of sectoral biomass energy consumption and status of biomass energy technologies in China.

2. BIOMASS ENERGY RESOURCES IN CHINA

Fuelwood, agricultural residues and animal wastes are the main sources of biomass energy in China.

2.1. Fuelwood

By the late 1980s, as shown in Table 2, China had a total of about 1230 billion m^2 of forest area out of which only about 36 billion m^2 was fuelwood forest. The government plans to establish an effective forestry development program for the country. Fuelwood plantations have been included as part of the forestry development plans at various government levels. It is reported that about 38 billion m^2 of new fuelwood plantations were created during 1980 [4]. Moreover, in the Forestry Master Plan, it is indicated that by the year 2000, the total fuelwood forest area will be about 80 billion m^2 [2, 3].

Until now, most of the nation's fuelwood is collected as by-product from forests that have primarily served other purposes. The trend is expected to continue in the foreseeable future. It is estimated that a total of about 73 MTOE of fuelwood was used in the country in 1993 while only about 38 MTOE of fuelwood was considered to be the collectable yield of the total forest areas in 1990.

Table 2. Fuelwood product of different type of forests in 1990 [2, 3].

Forest types	Areas (10^8 m^2)	Product (10^7 kg)	MTOE
Fuel wood	360.00	2868.84	11.30
Timber	8242.19	4486.22	17.61
Windbreak	1524.00	699.91	2.75
Economic trees	1450.63	1313.91	5.16
Special forest	311.66	45.09	0.18
Bamboo	399.26	186.16	0.73
Total	12267.74	9610.13	37.73

The consumption pattern of fuelwood clearly indicates non-sustainable use of the forests. However, according to Koopmans [6], the potential production of fuelwood in 1994 was about 211 MTOE and is projected to reach to 226 MTOE by the year 2010.

2.2 Agricultural Residues

Agricultural residues are widely used throughout China for cooking and heating purposes, and contributed about 23.8% of the total rural energy consumption in 1993 [5]. It is estimated that about 106 MTOE and 0.7 MTOE of agricultural residues were used in the residential and industrial sectors, respectively in 1993 [2, 3].

The production of main agricultural products and the estimated energy potential of the agricultural residues generated in 1990 are given in Table 3. The total amount of agricultural residues produced was about 213 MTOE in 1990. It has been estimated that the total amount of agricultural residues consumed for energy in 1993 was about 107 MTOE. According to Koopmans [7], the consumption of agricultural residues in 1994 was about 96 MTOE and the potential production was estimated as 338 MTOE in 1994.

The crop straw and stalk generation in 1995, as estimated by the Ministry of Agriculture (MOA) of China and Department of Energy (DOE) of U.S.A. has been reported to be 604 billion kg [9]. It has been estimated that about 15% of this amount was left in the fields as fertilizer, leaving the remaining 513 billion kg for other uses. About 335 billion kg or 58.7% of the total generation was estimated to be potentially available for use as fuel.

Economic Assessment of Crop Residue Availability

The extent of economic availability of residues depends upon several factors. The results of a preliminary survey carried out by the MOA and DOE project expert team in selected provinces are shown in Table 4. A significant difference of collection cost was noted among the three provinces mainly due to variation in collecting radius and labor cost. In Zhejiang province, the collection cost has been reported to be 0.14 Yuan/kg to 0.2 Yuan/kg for a collection radius of 2 km. In Shandong, the collection cost was found to vary between 0.12 Yuan/kg to 0.22 Yuan/kg for a collection distance of 0.7 km to 3.4 km. In Sichuan province, for a collection distance of 3 km to 8 km, the cost has been reported to be in the range of 0.15 Yuan/kg to 0.2 Yuan/kg [9].

Table 3. Generation of agricultural residues in China in 1990 [2, 3].

Agri-Products	Residue	Product	Yield (10^7 kg)	RPR*	Residue (10^7 kg)	L.H.V KJ/kg	Moist % (wet)	MTOE
Rice		Paddy	19174.8					
	Straw			0.9	17257.32	13305	10.0	53.96
	Husk			0.25	4793.7	14654	13.5	16.51
Wheat	Straw	Grain	9935.6	1.1	10929.16	13943	13.0	25.81
Maize	Stalk, cob and husk	Grain	9882.3	2.0	19764.6	12569	20.0	58.38
Sorghum		Grain	568.2					
	Stalk			1.8	1022.76	14008	14.0	3.37
	Husk			0.21	119.32	14654	13.5	0.41
Millet		Grain	456.2					
	Straw			1.41	643.53	12460	18.0	1.88
	Bran			0.25	114.05	14654	13.5	0.39
Other grains	Stalk	Grains	1288.7	1.0	1288.7	14654	14.0	4.44
Ground nut	Straw	Fruit (with husk)	636.85	0.8	509.48	15910	10.0	1.90
Rapeseed	Stalk	Seed	695.82	1.5	1043.73	15500	5.5	3.80
Soyabean	Stalk	Grain	1110.0	1.6	1776.0	15910	4.5	6.64
Sesame	Stalk	Grain	46.63	2.0	93.26	15500	5.5	0.34
Sunflower	Stalk and palm-leaf fan	Seed (with husk)	137.37	2.0	274.74	15500	5.5	1.00
Flax Hemp etc.	Stalk	Fiber	109.73	2.0	219.46	15500	5.5	0.80
Sugarcane			5762.02					
	Bagasse			0.25	1440.51	14235	11.5	4.82
	Top and Leaf			0.01	576.20	15910	10.5	2.15
Tobacco	Stalk	Leaves	262.71	1.6	420.34	15490	7.5	1.53
Cotton	Stalk	Cotton with seed	450.78	3.4	1532.63	15910	4.5	5.73
Potatoes	Stalk	Potato	2768.1	1.0	2768.1	14235	12.5	9.26
Total					**66587.59**			**213.12**

* Residue to product ratio.

2.3 Animal Wastes

The share of animal wastes in the total biomass energy use in rural China is quite low; out of the total biomass energy supply of about 185 MTOE to the rural areas of the country in 1993, about 6.0 MTOE, i.e. about 3%, came from the animal wastes.

As shown in Table 5, based on animal population reported by Qingyu, et al., [2, 3] and dry matter production and age coefficient factors given by Zhenhong [1], waste production of selected animals in 1990 has been estimated to be about 69 MTOE (200 billion kg of dry matter). For the same animal population and using dry matter per animal as reported by Bhattacharya, et al. [10], dry waste production has been estimated to be about 218 billion kg for the same year.

Table 4. Residue of collection costs in three provinces of China in 1995 [9].

Description	Unit	Zheiiang	Shandong	Sichuan
Percentage of every straw use				
Raw material for paper	%	3.0	1	2.4
Forage	%	5.7	22	31.4
Fertilizer and collection loss	%	15	15	15
Available for energy	%	76.3	62	51.2
in which, burned as fuel	%	23.3	34	41.2
left in the field	%	53	28	10
Total	%	100	100	100
Collecting radius	km	2	0.7-3.4	8, 5, 3*
Collection cost				
Rice straw	Yuan/kg	0.15	0.2	0.15-0.2
Wheat straw	Yuan/kg	0.15	0.2	0.15-0.2
Cotton stalk	Yuan/kg	0.2	-	-
Rape stalk	Yuan/kg	0.14	-	-
Jute stalk	Yuan/kg	0.2	-	-
Corn stalk	Yuan/kg	-	0.12	-

* There are three types of collecting radius of straw and stalk in Sichuan Province: in plain area, less than 8 km; in mountain area, less than 3 km; and in hilly area, less than 5 km.

Table 5. Generation of animal wastes in China in 1990.

Animals	Livestock population (million heads) (a)	Annual dry matter (kg/h/year) (b)	Age coefficient (c)	Amount of dry matter billion kg (a x b x c)	MTOE
Pigs	362.41	300	0.8	86.98	30.01
Cattle	102.88	1000	0.7	72.02	24.85
Horse	10.17	750	0.7	5.34	1.84
Sheep	210.02	150	0.8	25.20	8.69
Poultry	2433.91	5	0.9	10.95	3.78
Total				200.49	69.17

[a] [2, 3]; [b], [c] [1].

The MOA/DOE project expert team estimated the waste generation in 1995 by three main domestic animals, cattle, pigs, and chicken to be 290 billion kg equivalent to about 100 MTOE on dry matter basis; out of this about 167 billion kg could be potentially recoverable [9]. The recoverable fractions of cattle, pig and poultry wastes have been reported to be 60%, 90%, and 20%, respectively.

3. BIOMASS ENERGY TECHNOLOGY IN CHINA

3.1 Cookstoves

In an effort to conserve biomass energy, China embarked on a national program on improved cookstove development in the early 1980s. The number of households that had adopted improved cookstoves reached 148.6 million at the end of 1991 [11]. As of 1990, over 100 research institutes and universities comprising about 1,200 research fellows and 14,000 technicians were involved in the development of improved cookstoves. Over 5,000 organizations, involving some 29,000 persons, were engaged in administrative and management activities related to stove dissemination. Some 140,000 technichians/workers participated in stove dissemination in the field. There were about 1,400 stove manufacturers, involving some 30,000 production workers. Thus, in total, more than 200,000 persons took part in improved cookstove development and promotional activities.

Many different designs of improved cookstoves have been developed in China; thermal efficiencies of which have been reported to be in the range from 28% to as high as 75% [11].

3.2 Biogas Technology

Considerable advances have been made in the development of biogas technology in China. In 1993, about 17.33 billion kg of dry animal wastes was used for energy; this is about 4% of total dry animal waste generated annually. Of the total dry animal waste used for energy, about 7.33 billion kg was used to generate biogas producing about 1466 million m^3 of gas [2, 3]. One recent estimate indicated that by mid-1990s, there were about 5.52 million biogas digestors producing about 1,799 million m^3 of gas annually [1].

It is reported that the Chinese Government has a plan to increase the number of biogas units to 7.55 million and 12.35 million by the year 2000 and 2010 respectively, corresponding to annual biogas generation of 2.26 billion m^3 and 4.0 billion m^3 in 2000 and 2010, respectively [1].

Economic assessment of a biogas plant in a breeding farm in Hangzhow shows the internal rate of return (IRR) of the project to be 13.88% or higher, suggesting that projects of this kind are viable [12].

3.3 Gasification

The government of China has been investing substantial amounts of resources on biomass gasification projects since 1979 and the Chinese engineers have designed and developed several gasifier models. Some of these models include Model ND-600, XFL, HQ 280 and HD-280B. All these models are manufactured in China and available in the market.

Presently more than 700 gasification plants are operating in China [2, 3]. It has been reported that the total annual energy production from the gasification plants is about 16,500 TOE [1].

Several village scale central gassification systems supplying gas to 100 to 200 households have been demonstrated. A total of 14 gassification systems are reported to have been disseminated in Shandong Province alone [12]. Depending upon the model (producing 600 m^3 to 1300 m^3 per day), the investment and operation cost of these systems is reported to be 0.16 to 0.38 million Yuan and 21,000 to 48,000 Yuan per day, respectively (1 US$ = 8.28 Yuan).

3.4 Densification

According to Qingyu, et al., [2, 3], in 1993, about 600 million kg of agricultural residues were used for the densification purpose. There are about 600 briquetting machines operating presently.

The technology of biomass densification by means of screw presses is mature in China, while piston press briquetting machines are also being developed presently. The capacity of screw press briquetting machines is about 100 kg/hr to 120 kg/hr. The raw materials commonly used for briquetting are rice husk, sawdust and agricultural residues.

About half of biomass briquettes produced is directly used as boiler fuel as substitute of coal, the other half being used to make charcoal. Generally, 3,000 kg of briquettes produce 1,000 kg of charcoal. The heating value of the charcoal is about 30,000 kJ/kg.

There are two problems regarding production and utilization of biomass briquettes that need to be solved. One is the life of the screw of the briquetting machine and the other is the utilization of the combustible gas produced in the process of making charcoal from briquettes. As a result of successful research carried out by Liaoning Institute of Energy Resources, a new design of extrusion screw made of special material (ceramic coating) has been developed. The life of the new screw approaches 500 hours. Utilization of the combustible carbonization gas is also being studied.

A screw-press extrusion briquetting machine of model JX-7.5 has been jointly developed by the Northwest Agricultural University and Wugong Light Industrial Machinery Factory, Shaanxi province, China. The machine uses straw, rice husk, sawdust, etc. as raw materials. A carbonizing furnace has also been developed to carbonize the briquettes.

4. SECTORAL AND TECHNOLOGY-WISE BIOMASS CONSUMPTION

Recently, an attempt has been made to estimate detailed sector-wise and end-use wise biomass energy use in China [2, 3]. For this purpose, the total biomass use was divided into two sectors: the industrial and commercial sector combined together and the residential sector. A summary of sectorwise biomass energy use is presented in Table 6. It is seen that about 94% of the total of biomass energy was utilized in the residential sector in 1993.

Table 6. Sectoral biomass energy use in 1993 [2, 3].

	Industrial and commercial sector		Residential sector	
	billion kg	MTOE	billion kg	MTOE
Fuelwood	28.18	11.06	156.62	61.47
Agri-residue	2.15	0.74	305.65	105.80
Charcoal	0.14	0.10	0.10	0.07
Animal waste	0.06	0.02	17.17	5.97
Total		11.92		173.31

Table 7 shows the estimated biomass energy consumption for different end uses. The residential sector consumed 61.47 MTOE of fuelwood in the year 1993. Out of this amount, about 57 MTOE of fuelwood or about 93% of the total consumption was in traditional and improved cook stoves. On the other hand, only about 11 MTOE of fuelwood was utilized by the industrial/commercial sector; more than half of this was used in furnaces and kilns.

As can be seen from Table 7, about 105 MTOE of agricultural residues was consumed by the residential sector in 1993. As in the case of fuelwood, most of the agricultural residues were used in cook stoves. The industrial/commercial sector consumed 0.74 MTOE.

Table 7. Technology-wise use of biomass for energy in 1993 [2, 3].

	Industrial and commercial sectors	% of M.C on W.B	MTOE/ year	Residential sector	% of M.C on W.B	MTOE/ year
Wood	A. Furnaces/kilns (for making bricks, tiles, ceramic etc.)		5.89	A. Stoves # Traditional # Improved		 25.51 31.40
	B. Commercial boilers	16-22%	1.18	B. Walls with flues for space heating	16-22%	2.59
	C. Commercial ovens		0.08	C. Kindling for coal stove		1.96
	D. Hotels		0.78	D. Other uses		0.008
	E. Restaurants and canteen		1.77			
	F. Drying tobacco		0.39			
	G. Fry green tea		0.29			
	H. Kindle a fire for melting iron stove		0.39			
	I. Other uses		0.31			
	Total		**11.06**	**Total**		**61.47**
Residues	A. Rice husk Gasification for electricity generation		0.03	A. Rice husk stoves B. Sawdust stoves C. Stoves	 14-16%	0.52 0.52
	B. Rice husk fried boilers	14-16%	0.03	# Traditional # Improved		45.00 58.85
	C. Saw dust fired boilers		0.03	D. Fire pit under ground floor for space heating		0.03
	D. Combustion furnaces	<12%	0.35			
	E. Gasifiers	<12%	0.09	E. Walls with flues for space heating		0.35
	F. Densification		0.21			
				F. Other use # Domestic gasifier # Supply pipe gas by gasification	 <12% <12%	0.35 173 TOE 1038 TOE
	Total		**0.74**	**Total**		**104.77**
Charcoal	A. Hotels		0.03	A. Charcoal stoves		0.01
	B. Restaurants		0.03	B. Chaffing dish	3-5%	0.06
	C. Dry casting mould and core	3-5%	0.03			
	Total		**0.09**	**Total**		**0.07**
Animal wastes	A. Biogas platns		0.01	A. Charcoal stoves	10%	3.45
	B. Biogas plant for Electricity generation		0.01	B. Biogas digester C. Supply pipe biogas from biogas plants		2.42 0.09
	Total		**0.02**	**Total**		**5.96**

Note: M.C. on W.B. stands for moisture content on wet basis.

The amount of charcoal consumed is quite low. This may be because of high price of charcoal compared with coal in China. A total of only 0.16 MTOE of charcoal was used in 1993. Of this amount, 0.1 MTOE was made from wood and the other remaining 0.06 MTOE was produced from briquettes. The main end uses of charcoal are shown in Table 7.

In 1993, the amount of animal wastes used for energy was about 6 MTOE on dry basis. Of this, 3.5 MTOE was natural dried cow and horse dung used as dung cake for cooking. The remaining 2.4 MTOE was used as raw material for biogas digestors. Some amount of animal wastes is used in the industrial/commercial sectors as well.

5. CONCLUSIONS

The estimated biomass energy consumption in China during the year 1993 was about 185 MTOE. The share of various biofuels in the total biomass energy consumption was: fuelwood - 39.2%; agricultural residues - 57.5%; animal wastes - 3.2%; and charcoal - 0.09%. The biomass energy consumption in the different sectors was: the household sector - 93.6% and the combined commercial and industrial sector - 6.4%. Most of the biomass energy (about 89% of the total) is consumed by cookstoves in China. It is estimated that a total of about 73 MTOE of fuelwood was used in China in 1993, while only a total of about 38 MTOE was the collectable yield of the total forest areas in the year 1990. Annually, about 213 MTOE of agricultural residues and about 200 billion kg of dry animal wastes would be potentially available as energy source in China. The population of China is expected to reach about 1.4 billion by the year 2010. The demand for fuelwood for energy is expected to reach about 89 MTOE in 2010, while the consumption was about 73 MTOE in the year 1993. It suggests that fuelwood will remain an important source of energy in China in the foreseeable future.

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