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Biomass energy in China and its potential

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Biomass is a significant source of energy in China today, particularly in rural areas. However, most current use of firewood and agricultural residues for cooking and heating brings with it detrimental effects of indoor air pollution and associated adverse health impacts. In addition, the time spent collecting biomass fuels creates a burden on women and children, which reduces their time available for more productive activities. The availability of clean, low-cost fuels for heat and power in rural areas based on modern biomass technologies could significantly increase living standards and would be helpful in promoting rural industrialization and the generation of employment in rural areas. In addition, since sustainable use of biomass leads to no net increase in CO_2 emissions, there would be global climate benefits arising from the widespread use of biomass. This article discusses the size of the biomass resource base in China, the current status of modernized biomass technology development, and near- and mid-term commercial targets for implementation of modern bioenergy systems in China. The article also describes some advanced biomass conversion systems that might play a role in China's energy system in the longer term. Finally, it describes current barriers and constraints on increasing the penetration of modernized biomass energy in China, along with some policy suggestions for addressing these.

1. Introduction

Biomass accounted for about 13 % of primary energy consumption in China as a whole in 2000 (Table 1). The fraction in rural areas, where most biomass is located, is higher – some 22 % in 2000 – but this fraction has been declining since 1980 (Table 2), reflecting the growing preference in rural areas (with growing incomes) for cleaner and/or more convenient energy carriers, including coal briquettes, LPG, and electricity (Table 3). While primary energy use is shifting away from biomass in rural areas, the quality of the energy carrier is of greatest importance to the user, not the primary energy source. If clean, convenient energy carriers (e.g., electricity and liquid fuels) were produced cost-competitively from biomass, these carriers would be as attractive to users as the same carriers made from other primary sources.

Most biomass in China today is not converted into modern energy carriers. The use of wood and agricultural residues by direct combustion for cooking and heating in rural areas typically brings with it adverse health and social impacts. The combustion systems used with these fuels tend to be inefficient and create high indoor levels of air

Table 1. Primary energy consumption in China in 2000

Primary energy source	Energy consumption (PJ)	Percentage
Conventional energy		
Coal	25,128	56.9
Crude oil	8,852	20.0
Natural gas	938	2.1
Large-scale hydro power	2,587	5.9
Nuclear energy	-	-
Total conventional energy	37,504	84.9
Renewable energy (RE)		
Traditional biomass	5,617	12.7
New RE	1,072	2.4
Total RE	6,689	15.1
Total	44,193	100.0

Source: NBS, 2001

Table 2. Rural breakdown of energy consumption in China

	1980	1987	1996	2000
Population (millions)				
Total China	987.05	1093.00	1223.89	1265.83
Rural China	795.65	816.26	864.39	807.39
Energy consumption (PJ)				
Total China	24,370	33,580	45,420	44,190
Rural	9,610	15,170	18,660	25,710
Commercial energy	2,900	6,970	12,230	20,100
Non-commercial biomass energy	6,710	8,200	6,430	5,620

Source: MOA/DOE, 1998b

Table 3. Changes in energy use in rural China

	1980	1987	1996	2000
Rural household energy use (PJ)				
Coal and coal products	1,084	1,746	2,959	5,218
Petroleum products	29	56	138	228
Electric power	88	147	853	1,616
Straw and stalk	3,428	3,885	3,516	2,277
Firewood	3,018	3,818	2,432	2,806
Subtotal	7,647	9,651	9,898	12,146
Rural industry energy use (PJ)				
Coal and coal products	820	3,621	5,075	8,314
Petroleum products	410	665	1,324	1,996
Electric power	467	733	1,882	2,770
Straw and stalk	264	498	478	513
Subtotal	1,963	5,517	8,758	13,593

Source: MOA/DOE, 1998b

pollution. Household members, especially women and children, are exposed to pollutant concentrations that exceed international standards by an order of magnitude [Fischer, 2001]. The adverse health impacts are suggested by the fact that respiratory disease accounted for 23 % of all rural mortality in 1998 (compared to 14 % of urban mortality) [NBS, 1999]. Determining the level of mortality directly attributable to indoor air pollution is difficult, but based on the available mortality data for chronic obstructive pulmonary disease, lung cancer, pulmonary heart disease and chronic pneumonia, one researcher estimates that air pollution accounts for 13 to 22 % of all rural mortality [Florig, 1997].

An additional drawback of biomass fuels is the time required for collecting the biomass. The greatest burden falls on women and children, reducing their time available for more productive activities, such as education and income-earning employment.

In addition to the well-documented problems of indoor air pollution and the daily drudgery of collecting biomass fuel, a new severe air pollution problem associated with biomass is on the rise in rural China: the open-field burning of crop residues at harvest time. Traditionally, in poor agricultural communities of China, residues were fully utilised for heating, cooking, soil maintenance, and other purposes. But as rural incomes have risen, growing numbers of farmers have become less willing to gather residues from the fields and store them for use throughout the year – preferring instead to buy coal briquettes or LPG (Table 3). As a result, excess crop residues that do not readily decay (because they dry out too quickly for incorporation into the soils) are being burned off the fields to avoid insect infestation problems. The resulting air pollution has been severe – often even closing airports near harvest time. As a response, the government in 1999 banned burning crop residues near airports, railroads, and highways. The ban will be difficult to enforce, however, unless alternative productive uses can be found for residues.

China's biomass energy resources are substantial (see Section 2), and there are a variety of existing and future technological options for cost-competitively improving the efficiency and reducing the negative environmental impacts of biomass energy use by converting the biomass

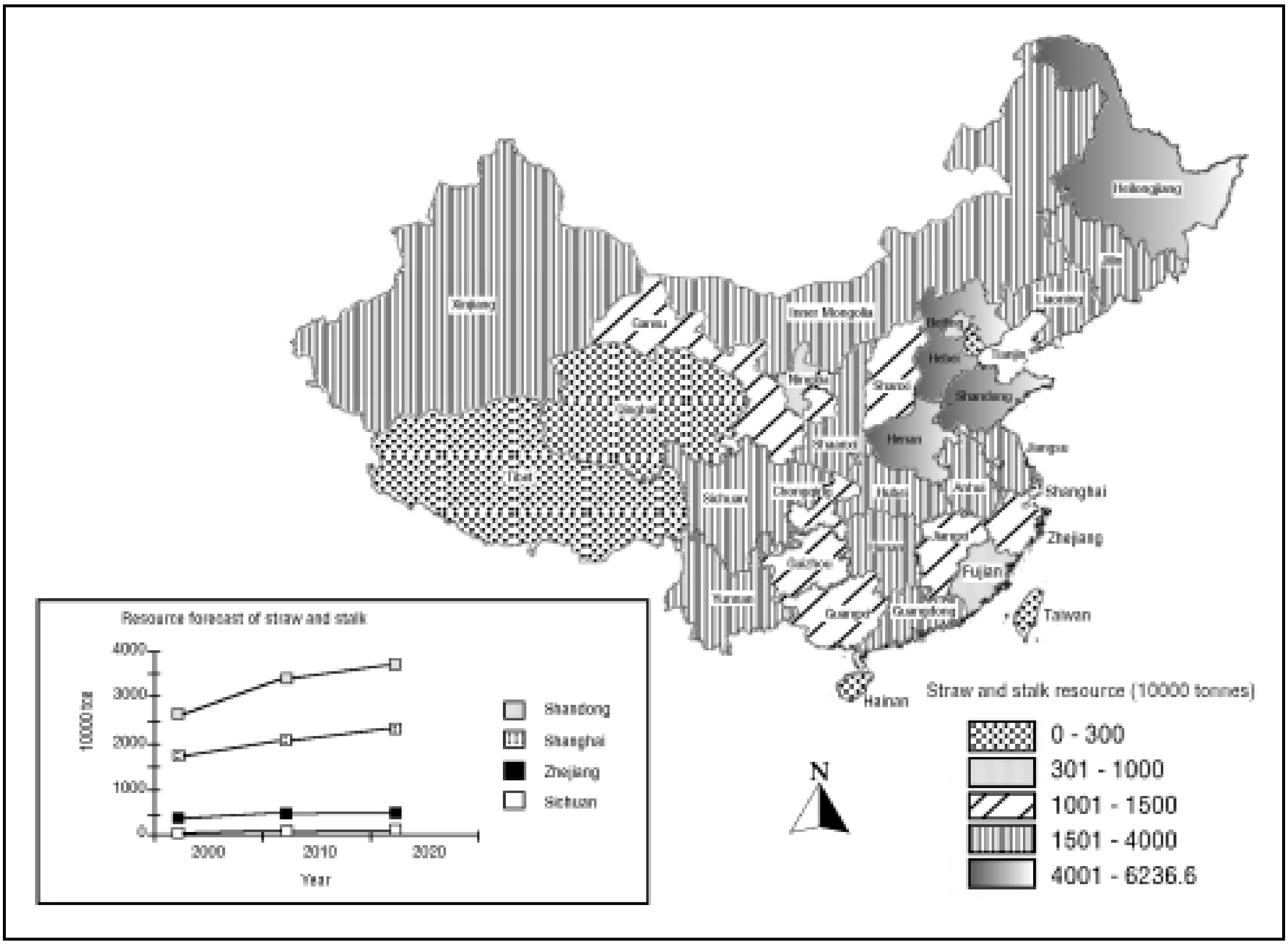

Figure 1. Distribution of agricultural residues by province. The unit used in the graph is tce (tonnes of coal equivalent). 1 tce = 29.3 GJ.

first into modern energy carriers, including electricity and clean gas and liquid fuels. The status of some key near-term technologies for modernizing bioenergy in China is reviewed in Section 3.

The availability of modern energy carriers from biomass in rural areas could significantly increase living standards and would be helpful in promoting rural industrialization and the generation of employment. In addition, since sustainable use of biomass leads to no net increase in CO_2 emissions, there would be global climate benefits arising from the more widespread sustainable use of biomass for energy to the extent that it displaces fossil fuels or unsustainable biomass use.

The potential for bioenergy to contribute significantly to meeting rural energy service demands in environmentally sustainable ways can be appreciated from the fact that in 1996, China generated crop residues in the field (mostly corn stover, rice straw, and wheat straw) plus agricultural processing residues (mostly rice husks, corncobs, and bagasse) totaling about 790 million tonnes (Mt), with a corresponding energy content of about 11 EJ [Gu and Duan, 1998], 25% of which was used for energy in 2000 (Table 3). To put this in perspective, if half of the total 790 Mt resource (equivalent to 11 EJ) were used for generating electricity at an efficiency of 25 % (achievable at small scales today with modern technologies), the resulting electricity would be equivalent to about 40 % of the total electricity generated from coal (China's primary energy resource) in 2000.

Such a magnitude of contribution from bioenergy can only be achieved over time. We discuss some near- and mid-term targets for implementation of modern bioenergy systems in China in Section 4. In Section 5, we describe some advanced biomass conversion systems that might play a role in China's energy system in the longer term. In Section 6, we describe current barriers to and constraints on increasing the penetration of modernized biomass energy in China, along with some policy suggestions for addressing these.

2. China's biomass energy resources

The principal biomass resources in China are: (1) residues from agriculture and forest industries, (2) animal manure from medium and large-scale livestock farms, and (3) municipal solid waste (MSW).

2.1. Agricultural and forestry residues

Agricultural and forestry wastes are the primary bioenergy resource generated in China, as their production is related to the main economic activity of a significant portion of the country. Table 4 summarizes the total amount of agricultural and forestry wastes generated in 1998. (Forestry wastes includes a small amount of wood from energy plantations. The potential for energy plantations in China needs to be better understood, including potential land-use and food production impacts.)

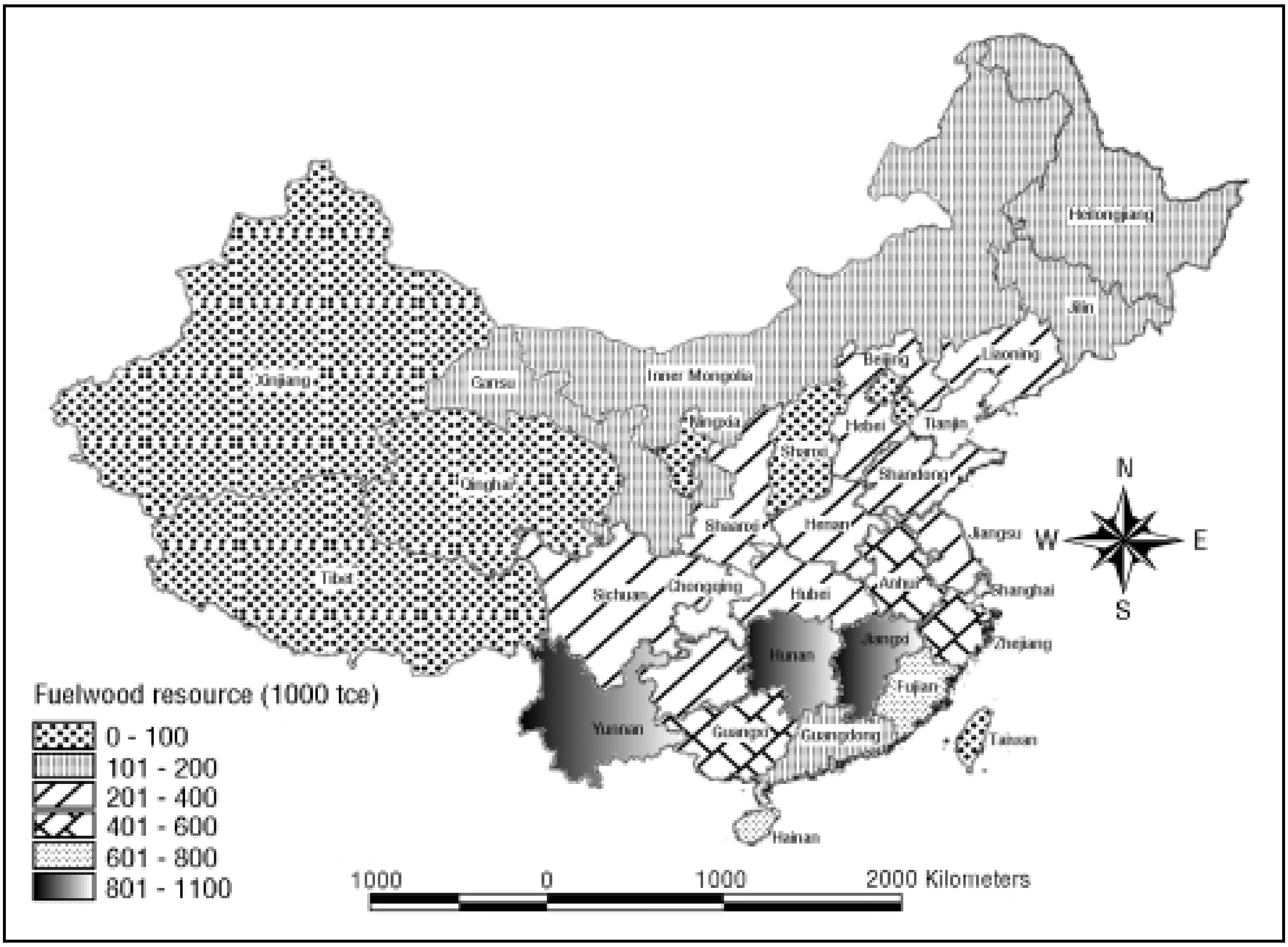

Figure 2. Distribution of fuelwood resources by province. The unit used is tce (tonnes of coal equivalent). 1 tce = 29.3 GJ.

Table 4. Estimate of agricultural and forestry residues generated in China in 1998

Residue type	Straw	Wood residues[1]	Rice husk	Bagasse	Total
Total amount generated (Mt)[2]	655.9	110.6	42.1	21.2	829.8
Lower heating value (GJ/t)	14.5	15.5	13.3	19.4	-
Energy value (PJ)	9,511	1,714	560	411	12,196

Source: CRED Team, 2001a

Notes

1. Wood residues refers primarily to residues from logging and forest maintenance operations. A small contribution from fuelwood plantations is also included.
2. From [NBS, 1999]

Currently, less than half of these wastes are used for some purpose, such as domestic heating and cooking, fertilizer, animal forage, raw material for paper, etc. The unused fraction of the residues generally exceeds the amount needed to maintain soil quality, and the field-burning of the excess residues constitutes a growing environmental hazard.

A main characteristic of this resource is that it is usually spread across an extensive area, and collection costs, especially for centralized use of these wastes, can be high. Some activities, such as sugarcane processing, involve a concentration of the resource as part of the normal processing activity and offer a clear opportunity for centralized utilization. In general, biomass resources are widely distributed and available in all regions of the country. (Figures 1 and 2 give the province-wise distribution of straw and firewood resources.)

2.2. Livestock manure

China has a long history of raising many species of domestic livestock. There are generally two methods of feeding. The traditional method, natural feeding, is mainly suitable for small-sized farms and families, and for specific animals, such as sheep, horses and ducks. With this feeding method, excrement is scattered in grasslands and pools and thus difficult to collect.

Concentrated feeding at large and medium-sized farms for cattle, pigs, sheep and poultry, has increased dramatically in recent years (Table 5). These livestock are generally reared in pens so that the excrement can be easily collected. Table 5 includes only the manure from these

Table 5. Estimate of animal manure resources generated in China

Year	Animal manure (Mt)[1]	Total energy (PJ)	Pig (PJ)	Cattle (PJ)	Chicken (PJ)	Sheep (PJ)
1991	396	815	50	142	623	0
1992	438	923	53	165	705	0
1993	576	1,318	57	206	878	177
1994	702	1,677	64	273	1,132	208
1995	840	2,057	73	331	1,391	263
1996	961	2,371	80	396	1,587	309
1997	870	2,343	68	337	1,691	247
1998	917	2,250	76	390	1,511	274

Source: CRED Team, 2000a

Note

1. From [NBS, 1999]

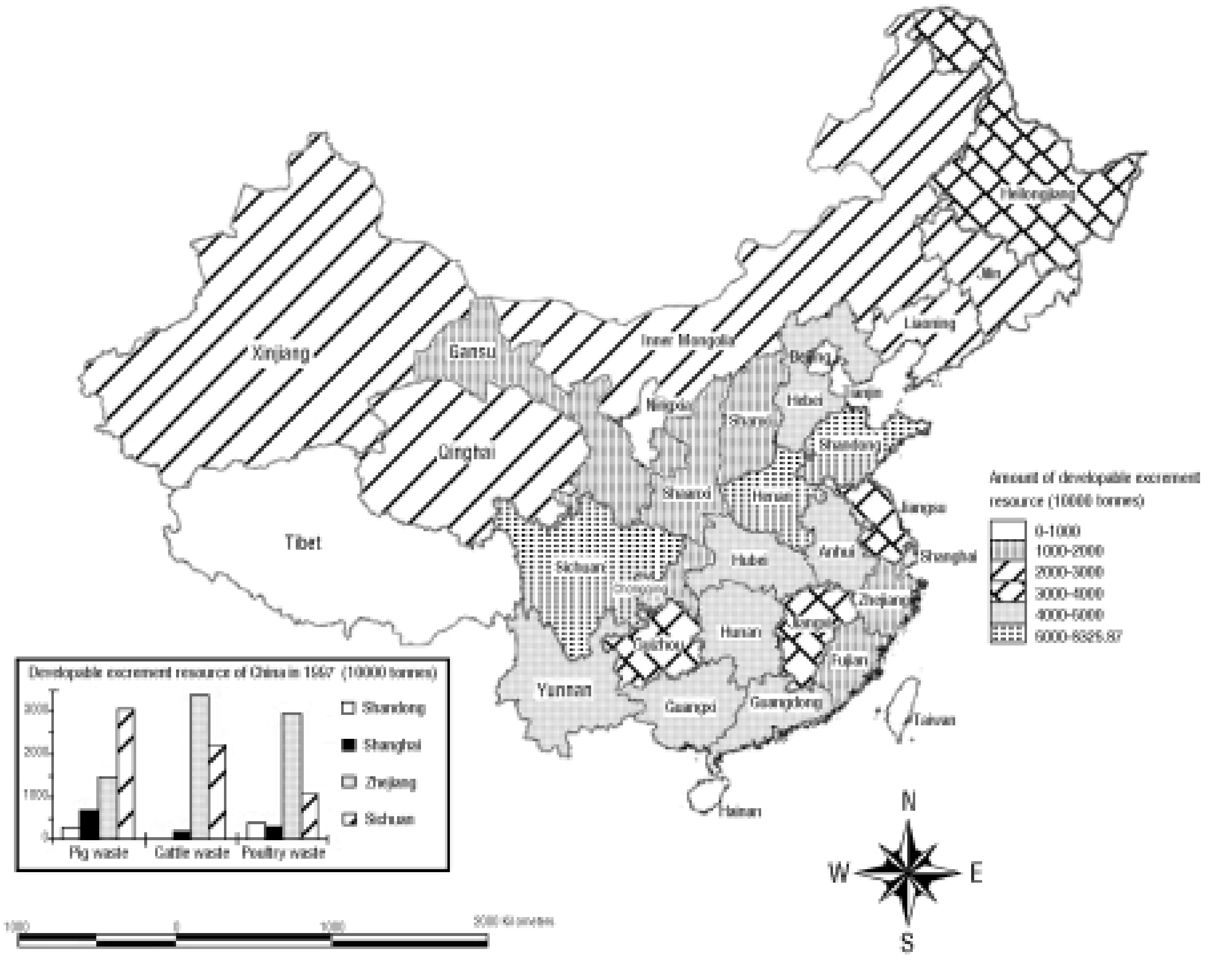

Figure 3. Distribution of animal manure by province.

medium- and large-scale livestock farms. The geographic distribution of this resource in 1997 is shown in Figure 3.

Table 6 provides an estimate of the energy potential of animal manure based on the typical lower heating value of the methane gas derived from anaerobic digesters processing the manure from each type of livestock. The amount of this resource that can be utilized depends on the manure collection efficiency [MOA/DOE, 1998a] as well as the energy conversion efficiency. The electricity potential is a modest 60.1 TWh.

2.3. Municipal solid waste

Disposal of municipal solid waste (MSW) in China reached nearly 300,000 t/day in 1995 (Table 7) and is expected to continue to grow as China's economy expands. The energy content of the 1995 level of MSW is about 1230 PJ.

Table 6. Estimate of potential electricity from animal manure, assuming the 1998 level of manure resources[1]

	Pig	Cattle	Chicken	Sheep	Total
Energy content (PJ)	76	390	1,511	274	2,250
Lower heating value (GJ/m^3)	23.0	24.0	21.2	23.0	-
Manure collection efficiency	0.9	0.6	0.2	0.6	-
Electricity potential (TWh)	5.7	19.5	21.2	13.7	60.1

Source: CRED Team, 2001a

Note

1. This calculation assumes the various manure resources (as in Table 5) have the energy contents and collection efficiencies indicated in this table. Conversion of the collected manure to electricity is assumed to be done with a 30 % conversion efficiency.

Table 7. Disposal of municipal solid wastes in China in 1995

Type	Quantity (10^3 t/day)	Percentage (%)
Surface dumping and simple landfill	232.5	78.95
Sanitary landfill	51.1	17.34
High temperature compost	7.1	2.41
Incineration	2.0	0.68
Others	1.8	0.62
Total	294.5	100

Source: MOA/DOE, 1998a

3. Status of modern biomass energy technology implementation in China

The two modern biomass energy technologies currently being utilized most widely in China are anaerobic digesters and small-scale thermochemical gasifiers. In addition, there are efforts under way to introduce modern combined heat and power production (cogeneration) technologies at sugar factories, where sugarcane bagasse is available as fuel. Construction of a facility for making ethanol from corn is also being planned.

3.1. Anaerobic digestion

Anaerobic digesters producing combustible biogas (a mixture primarily of methane and carbon dioxide) have been in use in China since the 1960s. The majority of digesters operating today supply single households, the original application of digesters in China. Building on the initial household applications, China has successfully developed digester technology for use with large and medium-sized domestic livestock and industrial and organic waste disposal facilities. There are currently about 6.4 million household-scale biogas systems producing some 1.6 billion m^3/year of gas and over 600 industrial-scale systems processing 40 Mt of waste annually to make 110 million m^3 of biogas. The industrial systems meet their host factory needs and also supply about 56,000 households with biogas for cooking. The projects are mostly located in the eastern part of the country and in the suburbs of large cities. Their location coincides with areas where there is rapid growth in concentrated animal breeding industries [MOA, 1997].

3.2. Household biogas systems

Traditional designs for biogas technology for rural households are well established and are commercially used in many regions of China. Since the original introduction of household digesters in the 1960s, many innovations have been made to improve the attractiveness of the technology to consumers. Such innovations are continuing. For example, a system being marketed in Yunnan province combines a digester producing biogas for household use with the toilet and pigpen commonly found in rural homesteads [Yin, 2001]. A variation on this “3-in-1” system is the “4-in-1” system that additionally includes coupling to a greenhouse, thereby allowing the digester to produce biogas even when ambient temperatures would normally be too low (as in winter) to support the digestion process. The 3-in-1 systems have been shown to increase productivity in raising pigs, and the 4-in-1 systems can provide additional income to the farmer through the planting of fruits and vegetables for sale.

3.3. Industrial biogas systems

The development of biogas projects on large and medium-scale animal farms in China began in the late 1970s and has closely paralleled both the scale-up of the breeding industry in China and the increased concern of Chinese society about environmental protection. Initially, biogas projects were built on animal farms to alleviate the severe energy shortage in rural areas. The rectangular or cylindrical digester was usually built underground, and because the digestion was performed at ambient temperatures, the volumetric biogas production amounted to only some 0.2 m^3 of gas/m^3 of digester volume per day. The residue was used as fertilizer with no treatment.

From the mid-1980s to the early 1990s, research was performed on digestion technology, construction techniques for the digester, and counterpart equipment in view of the increasing scale of biogas projects. The volumetric yield of biogas under normal temperatures approached 0.5 m^3/m^3 per day. The biogas projects on the Mianyang stock-breeding farm in Sichuan and the Dengta chicken farm in Hangzhou are examples. Meanwhile, advanced technologies were increasingly introduced from abroad and training and administration were enforced, which has led to further improvement of biogas technology.

Various types of technology have been introduced, including upflow anaerobic sludge blanket reactors, anaerobic filter reactors, and anaerobic contact digesters. Stirring devices have commonly been adopted, and some technologies have been designed for elevated temperature operation to promote higher gas output. The digesters were mostly built above ground out of concrete. Increasing attention has been paid to pretreatment. Special equipment for desulphurizing biogas has also been put into use. The issues of paying special attention to environmental protection (at the same time as exploiting energy resources) and of the adoption of comprehensive utilization were put forward for the first time, and administration was enforced. The design of most projects was standardized, and spot checks were made on completion of construction, before projects were officially accepted.

Since the early 1990s, more stress has been placed on the environmental benefits of projects. At the same time, the economic benefits of projects have been increased through comprehensive utilization. Comprehensive standards have been developed for system design and construction and for critical equipment. Good examples of successful biogas projects include those at the Xizi breeding farm in Hangzhou and the Tangwan breeding farm in Shanghai. One indication of the level of improvement that has been achieved to date in industrial digester systems is that the volumetric yield of biogas under medium temperatures now typically exceeds 1.0 m^3/m^3 per day.

3.4. Thermochemical gasification of crop residues

Thermochemical gasification refers to the conversion of lignocellulosic biomass into a combustible gas by heating it to relatively high temperatures. In gasifiers typical of those used in China today, some of the biomass is burned in air to provide the heat needed for gasification. Such air-blown gasifiers produce a gas, often called “producer gas”, that consists primarily of carbon monoxide and hydrogen as the combustible components. The energy content of the gas is typically only 10 to 15 % of that for natural gas as a result of the diluting effect of the nitrogen from the air, but the gas can be easily used for cooking, heating, and to run engines for shaft or electric power generation.

China began to research gasification technologies for wood wastes and crop residues during the l950s. In the early l980s, rice husk-based gasification systems, using a downdraft fixed-bed gasifier and a Chinese-manufactured engine-generator, were applied in the food industry with system outputs ranging from 60 kW to l60 kW. These systems were eventually discontinued because of the high maintenance costs and low reliability that resulted from contaminants (primarily “tar”) in the producer gas.

Research efforts were restarted in the mid-1980s to develop gasification systems for crop stalks and straw for centralized village-scale production of producer gas for supply of gas through a pipeline network to homes for domestic uses (primarily cooking). The Shandong Energy Research Institute developed down-draft fixed-bed gasifier systems capable of converting stalks of corn, sorghum, cotton, and soybean, as well as woody wastes. Gasification efficiency is reported to be between 72 % and 75 % in units producing 200 to 500 m^3/hr – large enough to serve 200 to 1000 households.

Research and development is also ongoing on more advanced gasification technologies, including those that deliver heat to the biomass indirectly, thereby avoiding nitrogen dilution, to produce a gas of medium calorific value (about one-third of the heating value of natural gas). The Dalian Academy of Environmental Sciences, the Chinese Academy of Sciences, and the Guangzhou Institute of Energy Conversion have been involved in these efforts [CRED Team, 2000b]. Some early demonstration systems based on these technologies are showing good potential.

3.5. Gasifier applications

As a result of the successful experience of the initial demonstration units in Shandong province, there are currently about 300 producer-gas systems operating in rural areas of several provinces. More than ten companies are currently engaged in the manufacture and supply of these village-scale cooking gas systems utilizing crop stalks. These gasification technologies have generally proven capable of providing a stable output of gas and reliable system performance. However, the economics of these systems are generally not attractive because they are operated only about six hours per day, which does not allow for sufficiently rapid recovery of invested capital. Government support has enabled the implementation of cooking gas systems essentially as social welfare projects.

A gasification system that is more economically attractive combines production of gas for cooking and heating with electricity production [WGEST, 1998]. Combining electricity generation with the provision of cooking and heating services increases the economic viability of the system by making more extensive use of the invested capital, as well as improving the overall efficiency of converting biomass into useful energy carriers. Because the national electricity grid extends to most rural areas in China, the economic configuration of a combined heat and power (CHP) system can be optimized through the supply of surplus electricity to the grid. Furthermore, with continuing market reform and electric-utility restructuring in China, power generation from decentralized plants under independent ownership will gradually become possible for economically viable technologies and approaches.

To help demonstrate the technical and financial viability of the CHP concept and help create the market and institutional forces needed for wide-scale replication of the concept, the Jilin provincial government, with co-support from the United Nations Development Programme, is currently undertaking a demonstration project in a village in the eastern part of Jilin [Liu et al., 2001]. The project goals are to establish the technical and economic viability of the CHP approach, to develop a business plan and commercialization strategy for project replication, and to identify and promote policy initiatives that are necessary for market-based development of follow-on projects.

3.6. A comparison of stalk gasification applications

The relative economic viability of alternative crop residue gasification applications is evident from the comparison summarized in Tables 8 and 9, which show, respectively, the technical and financial performance of alternative gasification systems each serving 200 households in a village. The first system provides cooking gas only. The second provides cooking gas and electricity. The third provides cooking gas, gas for heating in the winter, and

Table 8. Comparison of stalk gasification system applications: technical parameters

System parameter	Cooking gas	Cooking & electricity	Cooking, heating & electricity
Number of households	200	200	200
Gasifier size, m^3/hr	201	813	1,640
Operating hours/day	6	17	17
Annual output, m^3/yr	440,201	4,668,768	9,071,127
Biomass use, t/yr	250	2,656	5,160
Gas heating value, MJ/Nm^3	5	5	5
Gas to village-cooking, m^3/day	1,200	1,200	1,200
Gas to village-heating, m^3/day	-	-	12,000
Storage charge rate, m^3/hr	101	72	96
Storage size, m^3	124	214	434
Generator size, kW_e	-	200	200
Operating hours/day	-	17	17
Annual net output, kWh/yr	-	1,072,369	1,059,383

electricity. The performance and cost data for this comparison were developed on a consistent basis from data for a variety of projects in Shandong and Jilin provinces [Liu et al., 2001; CMOA/USDOE, 1998]. The two systems that generate electricity include a 200-kW capacity engine-generator operating 17 hours per day, with all electricity sold into the utility grid.

The addition of electricity generation significantly increases the gasifier size, and the annual gas output and biomass consumption increase by an order of magnitude (Table 8). The capital cost increases by a factor of four, and the O&M cost increases by more than a factor of 6 (Table 9). However, these cost increases are more than offset by the increased revenues from electricity sales, yielding a return on investment of 19 % compared to 4.4 % for the case with cooking gas only. The additional production of gas for winter heating doubles the gasifier capacity requirement, as well as the total gas production and total biomass consumption. The heating demand for a relatively cold climate (Jilin province) was assumed. (A similar result would be obtained for a warmer climate where an industrial process heat demand is being supplied rather than domestic heat.) The cost increases are again more than offset by increased revenues, pushing the return on investment to more than 30 %. Given the importance of revenues from electricity sales, the ability of such projects to obtain reasonable power purchase agreements will be a key requirement before there can be significant market growth in these types of plants.

3.7. Bagasse cogeneration

Approximately 21 Mt of sugarcane bagasse (the fiber remaining after juice extraction) and 10 Mt of cane trash (tops and leaves traditionally burned on the field after harvest) are produced annually in China, with sugarcane being processed in some 326 sugar mills. As in sugar mills worldwide, Chinese mills generate process steam and in some mills electric power for internal use by burning bagasse in low-pressure boilers. Traditionally, the low efficiency that characterizes this technology was desirable, as it insured that there would be no bagasse disposal problem remaining after supplying most or all internal factory energy needs. Selling excess power to the utility was not an available option for most factories.

The State Economic and Trade Commission recently estimated that between 690 and 870 MW of surplus power (in excess of factory needs) could be generated if all the existing boilers were replaced by modern high-pressure boilers feeding condensing-extracting turbines. At least double this level of power production would be feasible with biomass-gasifier/gas turbine cogeneration technology, a longer-term technology option that is not yet commercially available [Larson et al., 2001]. However, this potential market for modern biomass technology is yet to materialize because of the poor health of the sugar industry in China and because of a variety of market barriers. Many sugar mills are small and thus not highly economic. Of the 326 mills in operation, only 148 enterprises have a cane-crushing capacity greater than 2000 t/day. For comparison, state-of-the-art sugar mills in many countries have processing capacities of 15,000 t/d or more. A new program funded by the Global Environment Facility intends to support the commercialization of financially viable bagasse cogeneration plants in the southern provinces of Guangxi and Guangdong, which are the principal sugarcane growing regions.

3.8. Ethanol

Construction of the first major facility in China for making ethanol from biomass was recently announced. The intended use of the ethanol is as a gasoline additive. The facility will be built in Jilin province. It is expected to

Table 9. Comparison of stalk gasification system applications: financial parameters

Financial parameter	Cooking gas	Cooking gas & electricity	Cooking/heating gas & electricity
Prices			
Biomass feedstock, yuan/t	60	60	60
Ash/char, yuan/t	650	650	650
Cooking gas, yuan/Nm^3	0.20	0.20	0.20
Electricity sale, yuan/kWh	0.58	0.58	0.58
Electricity purchases, yuan/kWh	0.58	0.58	0.58
Capital cost (yuan)			
Site construction	20,100	81,320	164,000
Gasifier system	80,400	325,280	656,000
Gas distribution and storage system	255,611	296,266	395,336
Electricity generation system	-	397,200	397,200
Electricity distribution system	-	300,000	300,000
Site buildings	50,250	203,300	410,000
Auxiliary systems	20,100	81,320	164,000
Engineering	34,117	134,775	198,923
Other	47,163	186,313	274,991
Total installed cost	507,741	2,005,774	2,960,450
Operating cost (yuan/yr)			
Personnel	15,600	52,800	72,000
Feedstock	15,023	159,333	309,574
Electricity	3,906	-	-
Gasifier maintenance	804	3,253	6,560
Engine maintenance	-	13,902	13,902
Gas supply maintenance	639	741	988
Other maintenance	704	5,846	8,740
Taxes & fees	495	4,152	9,064
Total	37,170	240,026	420,828
Revenue[1] (yuan/yr)			
Gas for cooking	87,600	87,600	87,600
Gas for heating	-	-	876,000
Ash residues	11,392	120,827	234,760
Electricity to grid	-	621,974	614,442
Total	98,992	830,401	1,812,802
Overall financial indicators			
Net revenue, yuan/year	61,822	590,375	1,391,974
Unit investment cost, yuan/m^3/yr	1.15	0.43	0.33
Investment per household, yuan	2,539	10,029	14,802
15-year return on investment (%)	4.4	19	31

Note

1. The revenue calculations are based on established prices in Jilin and Shandong provinces for agricultural residues, cooking gas, and ash residues (as an input to organic fertilizer). The electricity price (0.58 Yuan/kWh) is similar to the price that has been granted to several wind farms and other renewable energy projects.

Table 10. Biomass projections of thermal applications

Technology	1998	2000	2005	2010
Household biogas systems				
Number (million)	6.40	6.90	7.30	7.70
Annual gas supply (Gm^3)	1.6	1.9	2.0	2.1
Energy equivalent (PJ)	38	44	47	50
Industrial biogas supply projects				
Annual gas supply (Mm^3)	110	130	160	200
Energy equivalent (PJ)	2.6	2.9	3.8	4.7
Crop stalk gasification projects				
Number	113	300	1,000	2,000
Annual gas supply (Mm^3)	70	160	610	1,290
Energy equivalent (PJ)	1.76	3.69	14.06	29.59

produce 600,000 t of ethanol per year from 1.92 Mt of corn once it begins operating in 2003. The facility will co-produce 45,000 t of corn oil, 175,000 M^3 of hollow bricks, and 183,000 t of materials for road-building. Jilin province is the country's number one corn producer with annual output of 15.36 Mt. The ethanol project is expected to consume one-eighth of the province's annual corn output.

The Chinese corn-ethanol program appears to be following in the footsteps of the program that has been in place in the United States since the 1970s. The US program is heavily subsidized by the government ($ 750 million in subsidies were paid in 1998), because ethanol made from corn has historically been uncompetitive with gasoline at prevailing prices for corn and gasoline [Larson, 1993]. The economics of corn-ethanol in China are not likely to be significantly different from those in the US., because producer corn prices in China are similar to those in the U.S., and the cost of the corn feedstock accounts for a significant share of the total ethanol cost. A more promising, but not yet commercially viable, option for ethanol production from biomass is one based on enzymatic hydrolysis to convert lignocellulosic biomass (a much lower-cost feedstock than corn) into ethanol [Lynd, 2001].

3.9. Municipal solid waste

At present, the two technology approaches being pursued in China for utilization of municipal solid wastes (MSW) are incineration and landfill gas extraction. A few MSW incineration demonstration projects have been built, with a total installed capacity of 15 MW in the year 2000. Utilization of biogas from landfills is still in the early stages of demonstration in China.

3.10. RD&D priorities in China

Research, development and demonstration project priorities in the biomass field planned by the Ministry of Science and Technology include: (1) a high-efficiency anaerobic digestion demonstration project with biogas power generation in the MW range, (2) an advanced biomass gasification and power generation project at a size of about 5 MW, and (3) technology development for liquid fuels from biomass and a 50-100 t/year demonstration project [Xu, 2000; Shi, 2000].

4. Near-term commercial potential of modern biomass energy

Under the Tenth Five-Year Plan (2001-2005), China plans to stimulate renewable energy commercialization and industrial development by focusing on market-oriented policies and programs for "mature technologies and products that own a certain scale of market and availability of profit" [Zhai, 2000]. Some biomass technologies meet these criteria.

Table 10 provides some projections to 2010 of the expected expansion in the number of biogas and producer gas projects (not involving electricity generation) [Xu, 2000; Zhai, 2000].

For projects involving electricity generation from biomass, the Center for Renewable Energy Development (CRED) has recently developed projections to 2020 as part of a broader assessment of the commercial potential for renewable energy over the next 20 years in China. The assessment used a marginal cost methodology to estimate the likely market penetration of different energy technologies, with the average cost of competing non-renewable electricity based on coal-fired power plants. Levelized energy costs were developed from investment, fuel, and O&M cost projections. The assessment evaluated the total system cost, including generation, transmission, and distribution. In the biomass sector, the projections for plant investment and operating costs were developed from both current data for the existing generation facilities in China and from recent projects in other countries [CRED Team, 2001b]. Table 11 presents the projections for the new increments of biomass power plants. For the straw and bagasse resources, the assessment included technologies for cogeneration, direct combustion, co-firing with existing coal boilers, and large-scale advanced gasification. As noted in the table, the capacity

Table 11. CRED projections of added biomass power capacity, 1998-2020

Resource	1998 installed capacity (MW)	Projected added capacity during indicated period (MW)			Capacity in 2020 (MW)	
		1998-2005	2005-2010	2010-2020	Projected installed	Potential capacity
Landfill gas	0	30	30	540	600	4,650
MSW	15	85	150	710	960	23,330
Biogas	2	25	125	150	302	630
Bagasse[1]	410	20	40	130	600	2,380
Straw	3	25	125	150	303	43,850

Note

1. The 1998 figure is the capacity of electrical generating equipment at sugar mills, almost all of which is consumed internally. The increments of new capacity are the surplus electrical generating capacity resulting from modern bagasse cogeneration systems.

projections for 2020 are far higher than the capacity that was installed in 1998, but they are also far lower than the estimated total potential.

5. Longer-term prospects for modern biomass use in China

The projections reported in Section 4 are based primarily on modest assumptions about the level of innovation and new technology development that will occur in technologies for converting biomass into modern energy carriers. A variety of advanced technologies that are at various stages of development in China or elsewhere might fundamentally change the nature and level of the contributions of biomass to China's energy future. A few of these technologies are briefly mentioned here.

5.1. Small-scale electricity and CHP technologies

Micro gas turbines in the range of 30 to 350 kW_e and having electricity generating efficiencies of up to 30 % (LHV) on natural gas are being commercialized for distributed cogeneration applications in the United States and elsewhere. In such applications, capital costs are minimized by use of low compressor pressure ratios, uncooled turbine blades, air bearings (in some designs), and other measures. The small scale of microturbines makes them well suited to mass production in factories, which further reduces cost.

Microturbines have the potential for being fueled with a variety of gases produced from biomass (producer gas, digester gas, and landfill gas). A few commercial installations have been built in California using landfill gas [LADWP, 2001], but the systems are complicated by the extra energy required to compress the relatively low energy-density gases to the required combustion pressure. Recent efforts to develop a form of microturbine that does not require external compression of the gas have reached the prototype stage, and will be demonstrated in the US over the next year [Prabhu, 1999]. A recent analysis by Hendrick and Williams [2000] of the potential for producer gas microturbines to provide heat and power to a village in Jilin province highlights the potential attractiveness of the microturbine technology in the rural Chinese context relative to currently available producer gas-engine technologies.

For the still longer term, a hybrid system that includes a solid-oxide fuel cell (SOFC) operating on gasified biomass, with fuel unconverted in the SOFC burned to power a microturbine bottoming cycle, would yield an efficiency approaching 45 % (HHV) at a scale of 200 kW_e, and potentially provide attractive economics in rural applications [Kartha et al., 1997].

5.2. Clean liquid fuels from biomass

A variety of clean liquid fuels can be made from biomass by first gasifying the biomass and then processing the resulting gas through systems similar to those designed for converting natural gas into liquids. Fuels that can be made in this way from biomass include methanol, dimethyl ether (DME), and Fischer-Tropsch liquids. DME is a particularly interesting fuel because it is well suited to meeting a variety of energy needs, including cooking, heating, transportation, and power generation. Small amounts of DME manufactured from coal are being used for cooking in China on a trial basis, but the predominant use of DME worldwide is as an aerosol spray-can propellant, replacing fluorinated hydrocarbons.

DME's properties as a cooking fuel are quite similar to those for LPG – at ambient conditions DME is a gas that must be stored at modest pressure, for example in canisters similar to those used for storing LPG. DME thus could use essentially the same delivery infrastructure that has already been developed for LPG in China.

DME has also been proposed as a vehicle fuel [Fleisch and Meurer, 1995]. DME is attractive for fueling diesel engines because of its high cetane number (an indicator of a fuel's suitability for compression ignition) and because its combustion produces no soot. Also, NO_x emissions are reduced considerably compared to the use of conventional diesel fuel.

For the production of DME from biomass to be economic, it will likely require facilities that are significantly larger than current village-scale cooking gas systems. Preliminary calculations presented by Williams [2001] indicate that a facility processing 350 t/day of agricultural residues could produce 60 t/day of DME and 10 MW of electricity at competitive prices. A single such facility could provide clean cooking fuel for over 70,000 rural households. Collection and transportation of the required quantities of biomass would be an issue, but would provide opportunities for employment and income generation among the rural population.

6. Constraints, barriers and policy recommendations

Proper biomass utilization requires attention to several general constraints that are especially important in China and other countries with developing rural infrastructures. From an environmental perspective, a key constraint to the sizing and siting of biomass plants is the availability of the resource and the cost of transporting the material, especially agro-forestry wastes. Significant environmental damage could result from improper management of the biomass resources (erosion, biodiversity reduction, landscape modifications, etc.), so sustainable management of the biomass resource is essential. Increased technical and market risks are often incurred because the plants must often be located in rural areas (where the resource is available) that usually are not well equipped with infrastructure, and where the level of technical sophistication is often not high.

6.1. Barriers

Like other renewable energy technologies, biomass energy conversion technologies are faced with many barriers and constraints to their commercial development. These barriers are discussed along the following categories: (1) technology, (2) funding, (3) market development, (4) economic incentives, and (5) energy management infrastructure.

6.1.1. Technical barriers

Many technical barriers are specific to the particular technology, but the general technical barriers faced by biomass technologies in China include the following.

- *Technical immaturity.* Most traditional Chinese biomass technologies have been focused on small-scale projects and only in recent years have medium- and large-scale energy projects begun to emerge. This evolving nature of these technologies creates significant risk for the suppliers and users.
- *Technology transfer.* Prevailing practices of technology transfer often do not sufficiently take into account the local conditions under which imported technology has to be operated and managed, the training required for its use, maintenance requirements and capabilities, and backstopping arrangements. Promoters need to consider both hardware and software aspects of technology transfer.

6.1.2. Funding barriers

There is a shortage of funds for biomass energy technology development in China. This makes it necessary to utilize the existing funds as efficiently as possible and to investigate possible mechanisms for raising special funds and attracting foreign investment. However, in the long term, the development of biomass technology in China must be done predominantly under market mechanisms.

6.1.3. Market development barriers

At present, the biomass energy market in China is not well developed. The technologies and organizational methods used to provide modern energy from biomass are not sufficiently developed to compete effectively with fossil-fuel options. Customers lack confidence in technologies, and project financing is often difficult to secure. In addition, because the market is at such an early stage of development, the demand-price reactions to social or political changes cannot be easily foreseen, adding further risk to projects.

6.1.4. Economic incentives

Experience in industrialized countries shows that effective economic incentives are needed to spur the development of a biomass energy market. Economic incentives in the current energy market typically do not account for environmental externalities, and thus tend to be biased against the adoption of modern biomass energy. Incentives are needed to overcome the market barriers that any new technology faces, and in the case of biomass these incentives should be well integrated with agricultural policy and programs. However, effective economic incentives have not yet been implemented in China.

6.1.5. Energy management infrastructure

Development of a new industry for modern biomass energy services requires significant business infrastructure development to design, build, operate and maintain such systems, to effectively manage the business operations, and to create customer awareness and understanding of appropriate levels of technology and service. One of the key steps in building this infrastructure is the development and promotion of standards and certification procedures by the government and professional technical societies that will allow the interested users to filter and determine the best technologies and enterprises.

6.2. Market development approach

China has considerable biomass reserves, it possesses a level of technical development commensurate with rapid market acceleration, and it has major rural energy needs that can be met at reasonable costs with modern energy carriers made from biomass. These needs can be met through market supply mechanisms, and the following approach is recommended for effective development of a modern biomass energy industry in China:

- continued government support and private sector involvement in biomass technology development and technology transfer;
- national and regional government incentives to stimulate commercially viable markets for modern biomass energy carriers;
- government and industry cooperation to formulate national technical specification and standards that will help create customer confidence;
- fiscal policy at the national, regional and local levels that supports investment in modern biomass energy systems;
- state support for the integration of regional and local biomass energy development planning; and
- government monitoring and regulation of the market development for modern biomass energy carriers.

China has several power-sector laws in place that promote the development of renewable and other clean sources of power, especially in regard to rural power development

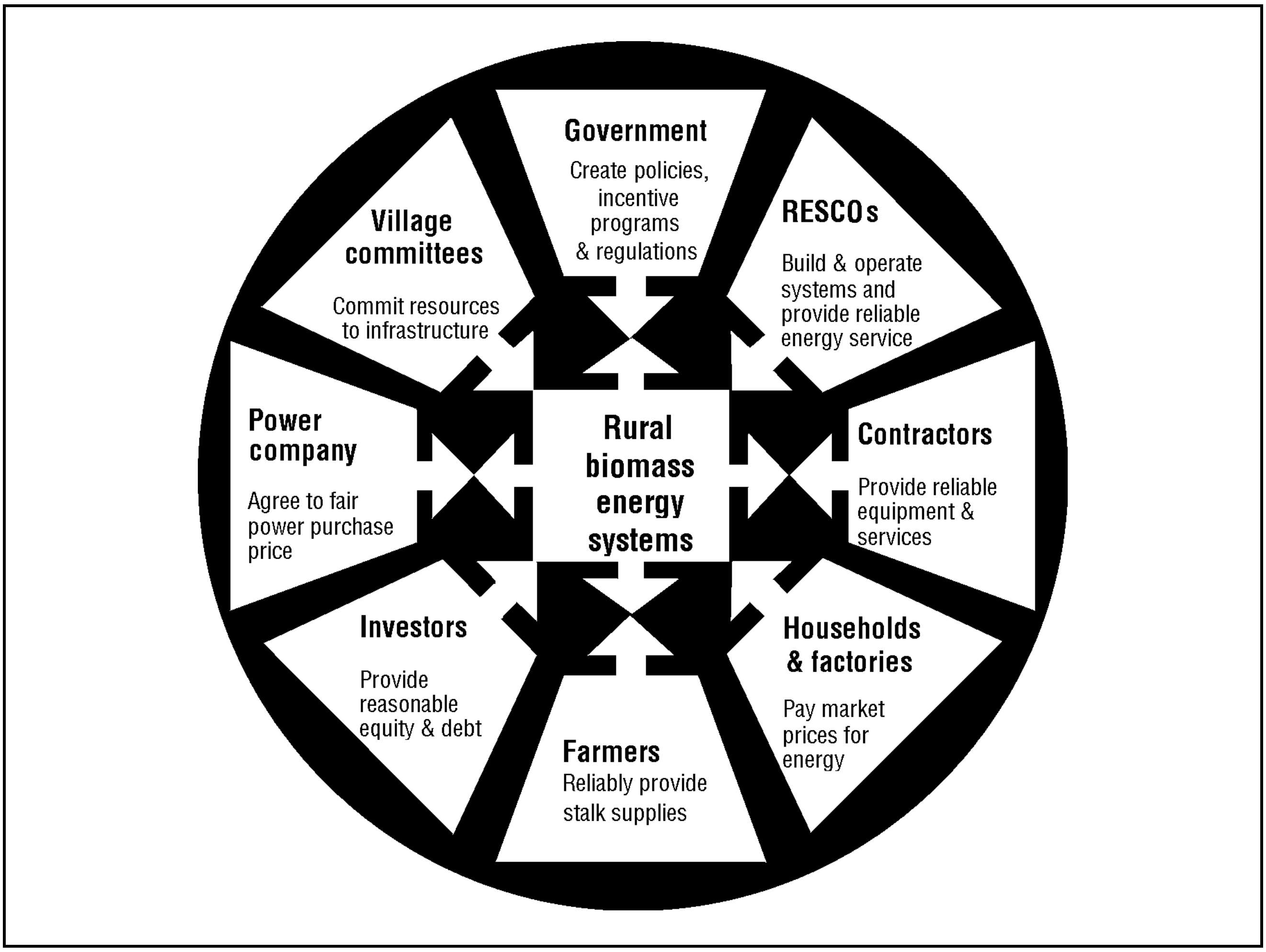

Figure 4. Actors in successful development of a market for rural modern biomass energy systems

and agricultural power usage. China has also passed energy saving laws stressing the strategic benefits of renewable energy as a main mechanism to reduce emissions and improve the environment. However, the biomass sector and the other renewable energy sectors need specific policies and programs for implementing each of these steps discussed above.

6.2.1. Technology development and transfer

Modern biomass technology in China is still rather immature, and a focused government program for research, development and demonstration is needed to reduce costs, improve performance and mitigate risks. Important progress has already been made in the areas of household and industrial biogas systems, village-scale crop gasification systems, and bagasse cogeneration, and more needs to be done in these areas. New areas of focus should include larger-scale biomass gasification systems and biomass-derived liquid fuels, such as DME and ethanol from enzymatic processes. Research and development in these new areas should focus on identifying several cost-effective options that satisfy both biomass resource availability and customer needs. Demonstration projects must be structured to evaluate both the technology and the development of viable businesses and markets.

Capacity-building within the existing and newly-emerging segments of the Chinese biomass energy industry needs continued support. At present, there are new initiatives focused on industrial biogas and village gasification projects, which are providing experience for technical and business development capacity-building. For more advanced biomass technologies, where the key technical equipment is provided by a foreign supplier, technical capacity-building is needed along with focussed efforts to incentivize local equipment manufacturing through collaboration agreements with technical experts and proven international technology providers.

In the emerging biomass energy markets (industrial biogas and village gasification), government programs must nurture and support the project development process, including activities to evaluate the sustainable biomass resource and to assess the local infrastructure needs and transport capabilities. In the longer term, assessments of energy crops for expanding the sustainable biomass resource base need to be made.

6.2.2. Market incentives

The interactions among government and private sector entities needed for successful development of a viable market for rural biomass energy systems are illustrated in Figure 4.

The key to sustainable market development is that investors in new biomass energy plants must see reasonable returns on investment and manageable business risks.

Government programs, policies and incentives play a critical role in encouraging the other market players to fulfill their roles. Village committees must have confidence in the technologies and suppliers in order to commit resources to modern energy systems. Power companies must be willing to enter into fair power purchase agreements for projects that include sales of electricity to the grid. Farmers must be willing to assure reliable biomass supplies. Rural households and factories must be willing to pay market prices for modern energy services. Contractors must be able to provide reliable equipment and services, and system suppliers (rural energy service companies – RESCOs in Figure 4) must be able to provide reliable services.

There are three general approaches, which have been used successfully elsewhere, that could be used to incentivize renewable energy markets in China.

First, government regulations could create a special power purchase program that will stimulate the market for clean energy technologies with guaranteed power purchases at attractive rates. This type of approach was successfully used in California in the 1980s to jump-start an industry for wind, biomass and cogeneration technologies. The Germans, Danish and Japanese have used a similar approach to grow wind and solar industries in their countries. Such a program in China would ensure rapid and robust industry growth for the advanced technologies identified in this paper.

The second approach, modeled on the concept of system benefit charges now in place in the United Kingdom and in parts of the USA, would establish a small fixed surcharge on all electricity sales. The surcharge would fund programs to stimulate construction of new biomass (or renewable) energy systems through buy-down grants, loan guarantees, or a variety of other measures (competitive bids in the UK). This approach is best suited to emerging technologies that have strong social and environmental benefits, but which may not be at present cost-competitive against the conventional energy technologies.

The third approach, called a renewable portfolio standard (RPS), would require all electricity suppliers to ensure that a minimum portion of their entire energy supply was met by renewable energy systems. The type of renewable energy used would not be specified, only the total amount, and the mix of technologies would be tailored by the supplier according to the most cost-effective choices available in that region. Competition for projects would help ensure that the lowest-cost projects are given priority, and if the purchase price is higher than the average power cost on the grid, then the price difference would be shared by the entire grid. This approach, which is best suited for relatively commercial technologies, is discussed in more detail by Jaccard [2001] in this issue.

Tax policy can also be used to help stimulate biomass energy systems. Renewable energy systems generally have higher capital costs and lower fuel costs than conventional technologies. Therefore, value-added taxes treat renewable technologies unfairly, because capital is taxed, but fuel is not. Two renewable energy technologies receive favorable value-added tax treatment in China: small hydropower (value-added tax rate is 6 % compared to the normal 17 %) and industrial biogas projects (value-added tax rate is 3 %). This favorable tax treatment needs to be extended to all biomass (renewable) energy technologies.

6.2.3. National standards and specifications

Meeting national technical specifications and standards should be a basic requirement of a technology for commercialization. Viewed from the current specific situation of biomass technology development in China, there is a need to formulate and compile technology specifications and standards for large-scale biogas engineering and landfill gas generation engineering. These should be worked out over a limited period with intensive attention by government and technical specialists. In addition, stronger organization of professional biomass researchers and other technical experts needs to be promoted through additional biomass energy research grants and support for high-quality professional education and training.

6.2.4. Project finance support

Most biomass energy systems, whether they are household biogas systems or large bagasse cogeneration projects, need some form of financing to cost-effectively meet capital requirements. Since 1987, the government of China has operated a special financial program (of several billion yuan per year) paying the interest on loans for rural areas for, mainly, industrial biogas projects, solar energy, and wind power. This type of program should be extended to village-scale biomass projects.

In 1999, the State Development Planning Commission (SDPC) and Ministry of Science and Technology (MOST) promulgated Decree #44, "Decree on some issues of how to sustain the development of new and renewable energy (N&RE)". It stressed that N&RE projects should have priority access to capital construction loans. Initially the loans would be mainly from the state development bank, but the decree encourages commercial banks to join actively. For large and medium-sized N&RE power generation projects (scale greater than 3 MW), the SDPC will help the developer to secure loan guarantees; power generating projects approved by commercial banks can get a 2 % interest subsidy. Central projects should get interest subsidies from the central government and locally from local government. A 1996 decree (#461) from the former Ministry of Electric Power and relating to enforcement of N&RE power purchases by the grid has been expanded from the local regional grid to the whole grid.

6.2.5. Integration of biomass energy and regional development

Sustainable utilization of biomass resources, especially agricultural residues, requires closer integration of the planning activities for food production, rural development and energy supply. The state government should encourage provincial and local government planning commissions to adopt integrated planning practices that support effective long-term management of local biomass resources.

6.2.6. Government monitoring and regulation

Several provincial governments have laws, rules and ordinances promoting the development of new and renewable energy technologies, such as modern biomass systems in local rural areas. Beyond the initial promotional role, the government will need to monitor the market development to ensure consumer and environmental protection, and adjust market incentives and programs as needed.

7. Summary

The long-term potential contributions of modern biomass energy carriers in China are significant. The primary energy in the biomass resources discussed in this article totals about 15.8 EJ (for 1998), which can be compared with total primary energy demand in China of about 48.6 EJ in 1998. If this level of biomass resource could be fully and effectively converted into modern energy carriers, significant improvements in rural living standards would be the likely result, including reduced health damage from air pollution from direct combustion of solid fuels for cooking and heating; reduced time spent by women and children for collecting biomass fuel, leaving more time for productive activities such as education and income generation; increased direct employment opportunities associated with the infrastructure for biomass collection, conversion, and delivery; increased rural industrialization (and associated employment) facilitated by the greater availability of clean, convenient energy carriers; and increased availability of liquid transportation fuels (e.g., ethanol or DME). New policies and programs are needed to address institutional barriers to expanding the use of modernized bioenergy in China, and to ensure that biomass is used for energy in environmentally-sensitive ways. ■

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