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Utilization of straw in biomass energy in China

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Abstract

China is a big agricultural country and one of the most abundant straw resources in the world, producing more than 620 million tons of straw in 2002, and representing about 33–45% of energy consumption for livelihood in rural areas. Utilization of straw as energy with high efficiency and rationality not only meets the demands for energy as the economy grows, but also provide a basis for environmental protection and sustainable development of society in China. This paper reviews the present utilized technologies of straw in biomass energy, including improved stove, biogas, straw gasification and straw briquette, which are already commercialized and popularized in China. Other technologies, such as liquefaction, straw carbonization and bio-coal, are also presented. Based on the technology status and potential, the future research and development of straw in the biomass energy portfolio in China are proposed.

Keywords: Straw; Biomass; Biomass energy; Improved stove; Biogas; Gasification; Briquette

Contents

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1. Introduction

Biomass is the first energy source harnessed by mankind. It remains the primary source of energy for more than half the world's population, and accounts for 14% of the total energy consumption in the world [1]. As one of the most common forms of renewable energy, biomass is a low-carbon fuel and absorbs CO_2 in its production, and becomes a sink for the greenhouse gases. Biomass therefore is likely to be an attractive clean development mechanism (CDM) option for reducing greenhouse gas (GHG) emission [2].

As a big agricultural country, China has an abundant biomass energy resource, which is usually classified into four main categories: straw, firewood, various kinds of organic wastes and agricultural residues. Straw is the most part of the biomass energy resources, which accounts for 72.2% in China. Now, direct combustion of straw is the main utilization of biomass energy in China, which leads to many problems. On one hand, in some regions that are short of straw, large quantities of firewood have been cut as supplementary fuels for the low combustion efficiency of straw. This causes serious damage to the local ecological environment. On the other hand, there are relatively enough commercial energy in some well-off regions, lots of straw has been discarded, even burned in the fields, which makes waste of resource and pollution of environment. Therefore, more and more attention are focused on the utilization of straw with high efficiency and rationality in China.

2. Straw resources in China

Straw often refers to the residues or by-productions of the harvesting crops. Because the yield of straw has not been listed in the range of some department's statistics in China, it is often estimated by the product yield of crops. Tables 1 and 2 list the resources and distribution of the main straw in China [3]. The coefficients giving the residue yield/product are derived mainly from the MAO/DOE Project Expert Team [4] and are given in Table 1. The coefficients represent the average values of residue yield/product for the main Chinese agricultural crops.

Shown in Tables 1 and 2, the total output of the crop straw was 622 million ton in 2002, and straw of rice, wheat and corn was 109, 121 and 243 million ton, respectively. The three kinds of straw were about 76.1% of the total crop straw resources. The most part of straw was corn, accounting for 39.12% of the total straw, North (Hebei and Inner mongolia) and Northeast (Liaoning, Jilin and Heilongjiang) and parts of East (Sandong) and Central South (Henan) of China were the main producing areas. The second was wheat, which accounted for 19.45% of the total straw and mainly came from East (Sandong, Jiangsu

Table 1
Tonnage of straw by crop categories in China in 2002 (Unit: 10^6 ton) [3]

Crops	Yield of Crops	Coefficient [4]	Yield of straw	Percent (%)
Rice	174.54	0.623	108.74	17.53
Wheat	90.29	1.336	120.63	19.45
Corn	121.31	2	242.62	39.12
Beans	22.412	1.5	33.62	5.42
Tubers	36.659	0.5	18.33	2.96
Oil-bearing crops	28.972	2	57.95	9.34
Cotton	4.916	3	14.75	2.38
Hemp	0.964	2.5	2.40	0.38
Sugar crops	102.927	0.1	10.29	1.66
Other crops	10.941	1	10.94	1.76
Total			620.27	100

and Anhui), Central South (Henan) and North (Hebei) of China. The third was rice, accounting for 17.53% of the total straw and teeming in Central South (Hunan, Hubei, Guangdong and Guangxi), East (Jiangsu, Jiangxi, Zhejiang and Anhui) and Southwest (Sichuan) of China. Others were beans, tubers and oil-bearing crops, accounting for 5.42%, 2.96%, 9.34%, respectively. With the structure adjustment of the planting industry, the straw output of economic corps will increase in the future.

3. Main utilization of straw in biomass energy in China

China is abounding with straw, and the yield of straw has increased at a rate of 1.4% annually. The main approaches to straw utilization in China are papermaking, forage, rural energy resource, and recycling in field and collection (including some losses), accounting for 2.1%, 28%, 53.6% and 16.2%, respectively [5]. Therefore, energy resource is over the half of straw utilization, even 100% in some poor rural areas. The Chinese government has attached high importance to the development and utilization of biomass as an energy resource, and has conducted long term and wide ranging research and development on the latest biomass energy conversion technologies through the National Program for Key Science and Technology projects since 1950s, through hard work of many years, great results of straw as energy have been obtained in direct combustion, biochemical and physicochemical conversion, including improved stove, biogas, gasification and briquette. These technologies are already commercialized and popularized in China. The present utilization of straw in biomass energy has been made in the following aspects.

3.1. Direct combustion

Direct combustion of biomass is the main and traditional way of the utilization of biomass energy. Table 3 lists straw as energy for livelihood in rural China from 1991 to 2000 [6,7]. With the living standard level of rural increasing recently, some changes have taken place in the structure of rural energy, but straw is still one of the main fuels in rural, accounting for 33–45% of energy consumption for livelihood.

Table 2
Tonnage and distribution of main crop straw in China in 2002 (Unit: 10^4 ton) [3]

Regions		Rice	Wheat	Corn	Beans	Tubers	Oil-bean corns	Cotton	Fiber crops	Sugar crops
North of China	Beijing	2.9	24.3	46.1	4.0	3.7	4.6	0.3	0	0
	Tianjin	11.2	44.1	71.1	5.7	0.9	3.40	6.2	0	0
	Hebei	55.7	1099.5	1035.0	60.6	119.0	151.3	40.2	1.0	14.7
	Shanxi	2.0	243.2	435.3	49.4	99.9	38.4	7.5	0	18.5
	Inner Mongolia	56.0	121.5	821.5	139.9	168.5	108.9	0.3	1.0	195.0
Northeast of China	Liaoning	406.2	11.5	858.0	56.9	61.0	56.5	0.3	0	39.8
	Jilin	370.0	7.9	1540.0	185.0	41.7	46.1	0	0.8	76.2
	Heilongjiang	921.0	89.4	1070.5	610.7	135.0	52.8	0	36.2	437.6
East of China	Shanghai	109.2	10.4	3.0	3.5	0.5	9.9	0.1	0	8.7
	Jiangsu	1709.9	644.5	261.7	105.9	98.5	217.0	36.3	0.5	34.7
	Zhejiang	779.6	25.4	22.3	41.9	58.1	47.0	2.2	0.2	113.4
	Anhui	1327.5	683.7	356.8	147.4	185.3	282.3	33.7	4.6	31.3
	Fujian	557.5	6.7	11.2	26.4	156.6	25.9	0	0.1	117.9
	Jiangxi	1451.6	4.3	5.5	29.9	56.7	82.4	6.7	1.6	130.8
	Shandong	109.4	1547.1	1316.0	76.4	221.9	340.4	72.2	0.6	0.2
Central south of China	Henan	336.5	2248.4	1189.8	115.4	266.9	420.7	76.5	5.4	27.9
	Hubei	1469.8	151.2	187.4	64.7	159.1	245.3	33.2	6.5	91.9
	Hunan	2119.2	18.3	119.2	61.2	171.7	119.3	15.3	13.6	180.4
	Guangdong	1202.8	3.2	53.5	24.0	186.7	76.4	0	0.2	1315.5
	Guangxi	1219.3	1.8	161.0	40.3	62.2	56.0	0.1	1.2	4593.4
	Hainan	139.3	0	5.1	3.2	40.0	10.0	0	0.1	374.8
Southwest of China	Chongqing	490.2	93.2	197.4	27.8	264.1	35.0	0	1.2	12.1
	Sichuan	1503.7	459.1	525.1	106.7	468.3	201.5	2.4	4.5	171.5
	Guizhou	347.8	87.0	343.2	40.8	204.5	72.5	0.1	0.2	74
	Yunnan	543.2	134.1	461.5	93.6	153.9	27.5	0	2.3	1733.7
	Tibet	0.6	27.8	1.7	3.4	0.2	4.5	0	0	06
Northwest of China	Shanxi	80.3	405.3	374.5	30.7	87.5	41.1	4.3	0.1	3.1
	Gansu	5.6	312.1	219.2	38.6	141.6	41.9	7.0	1.4	28.9
	Qinghai	0	45.2	1.2	10.9	24.4	23.4	0	0.4	0
	Ningxia	66.7	96.1	104.3	10.0	16.2	10.9	0	0	0
	Xinjiang	59.3	382.7	332.9	26.4	11.5	44.4	147.7	12.4	466.8
Total of crops output		17454	9029	12131	2241.3	3666.1	2735.6	491.6	96.1	10292.8
Total of straw output		10873.84	12062.74	24262	3361.95	1833.05	5794.6	1474.8	240.25	1029.28

However, the wide-ranging utilization of straw as energy for livelihood in rural areas of China was inefficient stoves. This caused many ecological and environmental problems. In 1980, the Chinese government has launched the National Improved Stoves Pilot County Programme (NISPCP) throughout the country with the aim of improving energy efficiency. Many engineers and technicians took part in the R&D in the initial phase of

Table 3
Straw as energy for livelihood in rural China (Mtce) [6,7]

Year	Rural energy consumption	Energy consumption for livelihood	Straw	Percent of energy consumption of straw for livelihood (%)
1991	568.22	360.03	162.13	45.0
1992	569.79	320.47	135.50	42.3
1993	585.00	350.11	153.54	43.9
1994	610.25	365.26	152.16	41.7
1995	665.05	381.72	150.92	49.5
1996	639.62	340.69	119.97	35.2
1997	655.85	427.12	121.39	34.4
1998	672.13	365.84	122.80	33.6
1999	630.32	353.46	125.02	35.4
2000	670.47	369.99	123.60	33.4

the diffusion programme. Some technologies such as shape of combustion chamber, size of feeding door, grate and ash pit have been contributed for the world [8]. The efficiency of improved stoves today has reached to over 20–25%, while the old ones only 10–12%. By the end of 2000, more than 189 million rural households substituted improved stoves for their traditional ones, which accounted for 78.4% in the rural households. An improved stove can save about 1–1.5 tons of firewood annually, amounts to 100–200 RMB. To build a new, improved stove costs 60–100 RMB, and the cost of the firewood saved every year amounts to over 100–200 RMB, which indicates that the investment costs for new stoves are recovered in one year. According to preliminary estimates, about 50 million tons of CO_2 emissions are avoided annually in China owing to the diffusion of improved stoves [9].

Some advanced technologies, for large-scale utilization of straw as fuels, such as fluidize-bed combustion, have been researched on generating electricity and supplying heat in China recently. The combustion efficiency of straw in fluidized-bed has been improved, and its performance is close to the traditional boiler, which uses coal, petroleum and natural gas as fuels. Because of long-term and large-scale use of chemical fuels, China acquires lots of fruits on the research and application technologies of chemical fuel. Therefore, on the base of these technologies, research on straw direct combustion in fluidized-bed is one of the effective and large-scale approaches to straw utilization, and is able to gain benefit on energy as well as environment.

3.2. Anaerobic digestion

Anaerobic digestion (or biogas technology) is a bioconversion technology widely adopted in China, especially in rural areas. Mixed with straw, human wastes and animal dung and organic wastes in certain proportion, biogas can be obtained in the condition of anaerobic environment. The main composition of biogas is CH_4, accounting for 60–70%, and its heat value is about $2.5 \times 10^4\,kJ/m^3$, equivalent to 1 kg raw coal or 0.76 kg standard coal. There were 7.64 million household biogas digesters by the end of 2000. Fig. 1 shows the development of household biogas digesters from 1985 to 2000 in China [9,10].

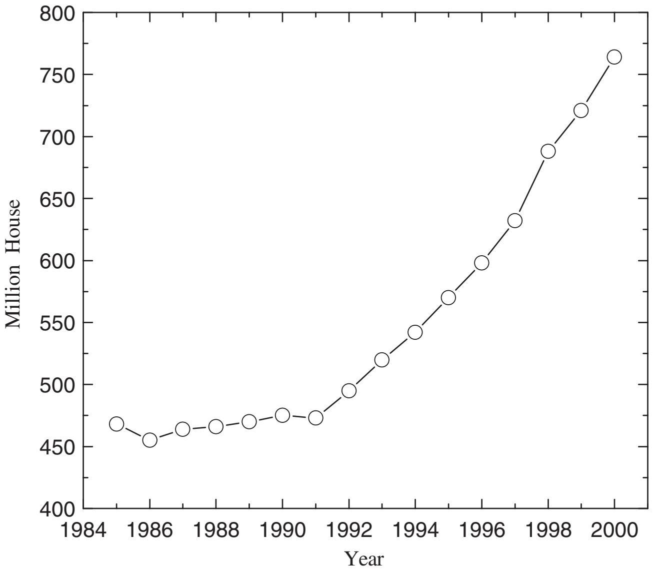

Fig. 1. The development of household biogas digesters in China in 1985–2000.

The biogas output was over 2.274, 31.46 and 37.49 billion m^3 from 2000 to 2002, respectively [3].

Since mid-1980s, farmers began to build biogas digesters self-funded with small proportion of collective subsidy in China. Standardized technical guidance has been strengthened after that period. New technology and new products like biogas lamp and stove pressure meter have entered into hundreds of thousands of families. The widely used biogas digester in rural areas is hydraulic biogas digester, accounting for 90%, and noted in the world for "China's model of biogas digester". It has the characteristic of compacted structure, convenient transportation and use, and low construction cost. Because of its some disadvantages including high pressure of fluctuation (4–6 kPa), difficult discharge and low gas productivity 0.15 $m^3/(m^3.d)$, new types of biogas digesters, meandering, up-flow, plug-flow, tower and floating, have come into being recently. These household biogas digesters have high gas productivity 0.3–0.9 $m^3/(m^3.d)$, low construction cost, simple maintenance and management, long operation life and easy popularization. The coverage and technical level of biogas in China takes the lead among developing countries.

Biogas is an applied eco-agricultural technology. The comprehensive utilization of biogas by integrating the use of residues from livestock production and straw can promote agricultural production and improve ecology and environment in rural areas. "Four in One" model is proposed in north China, which combines with biogas digester, pigpen, greenhouse and toilet. Biogas fluid can be used to grow vegetables, spray as leave fertilizer and control crop diseases and pests. Biogas can be used to increase the temperature of greenhouses and CO_2 concentration within them. With the temperature of greenhouses increased, vegetables can grow well and pigs are well-fed [11]. While in south China, "Three in One" pattern, such as "Pig–Biogas–Fruit", or "Pig–Biomass–Vegetable", or "Pig–Biomass–Grain" are very popular, in which livestock breeding and excrements from the breeding entering biogas digesters. Biogas can be a solution to household fuel; biogas fertilizer is used to grow fruit trees, vegetables and grain as well as a pest control agent. Green food can be developed from the pattern. In some regions, biogas engineering in livestock breeding farms is also popular: Chicken dung from henneries goes into the first anaerobic digester to realize biogas fermentation and its residues can be added to pig feedstuff in pig feeding. Pig dung enters the second anaerobic digester and biogas fermentation is conducted. Biogas fluid and biogas fertilizer flow into the ponds to raise fish. The remaining biogas liquid and biogas fertilizer can be used in vegetables and fruit trees as well as succulence. Biogas can provide breeding farms and food processing with energy and power.

3.3. Straw gasification

Straw gasification is a technology used for extracting gaseous fuel from straw in gasifier. Many countries have been interested in this technology of generating clean renewable energy. From the 7th to 9th Five-year Plan in China, hundreds of straw gasification demonstration projects have been built and operated successfully [12]. Different product biogas qualities can be produced from straw gasification by varying the gasifying agent according to the method of operation and the process operating conditions. The first biogas is low calorific values (CV) (4–6 MJ/Nm^3), using air and steam/air as gasifying agent [13], its essential component is CO. The second biogas is medium CV (12–18 MJ/Nm^3), which uses oxygen and steam as gasifying agent, the main elements are CH_4 and H_2, which can be used as fuels, and the industry production such as artificial charcoal and wood tar can be gotten as well. The third biogas is high CV (40 MJ/Nm^3), which uses hydrogen and hydrogenation as gasifying agent. Low CV biogas is used directly in combustion or as an engine fuel, while medium and high CV biogases can be utilized as feedstock for conversion into basic chemicals, principally methane and methanol. Medium and high CV biogases can also be utilized in fuel boiler or to generate electricity.

Over the past decade, there has been great progress in the development of gasification technology in China. Many kinds of biomass gasification processes have been developed treating different materials for various purposes. A remarkable progress is the economic production of circulating fluidized-bed (CFB) gasifier and down draft gasifier for straw. Table 4 shows the major types of gasifier applied in China.

Nowadays, there are more than 40 factories and enterprises that provide biomass gasification equipment and facilities in China. In order to promote the application and industrialization of straw gasification technology, some of excellent demonstration projects

Table 4
Major types of gasifier applied for straw in China [12]

Gasifier type	Fuel types	Output (kWe)	Low CV of gas (kJ/m^3)	Temperature (°C)	Efficiency (%)	Application fields
CFB	Straw, husk, sawdust	400–2000	4600–6300	650–850	65–75	Boiler fuel, electricity generation
Down-draft	Straw	60–200	3800–4600	~1000	75	Domestic cooking

Table 5
Typical straw gasification demonstration projects in China [12]

Project	Material	Purpose	Capacity	Gasifier	Location
Huantai integrate gas-supply system	Crop residues	Cooking	300 kWt	Down draft	Shangdong
Dalian integrate gas-supply system	Crop residues	Cooking	300 kWt	Down draft	Hunan
Handan steel works	Straw	Electricity	600 kWe	CFB	Hebei

Table 6
Investment and cost of straw gasification system for central gas supply in China

Number of household	Total investment (10,000RMB)	Household investment (RMB)	Low CV of gas (MJ/m^3)	Gas cost (RMB/m^3)	Gas price (RMB/MJ)
100	20.4	2040	5	0.150	0.0430
200	28.4	1420	5	0.130	0.0240
300	38.4	1213	5	0.103	0.0260
400	41.4	1055	5	0.096	0.0182
500	46.4	928	5	0.084	0.0168

have been built and operated successfully in towns and rural areas of China. Table 5 lists some of the earliest demonstration projects that have been successfully operating in China.

It is commercialization and industrialization of straw gasification system for central gas supply with low CV in China recently. By the end of 2000, 388 sets of straw gasification system for central gas supply had been built, which provides biogas about 150 million cubic meters, consuming straw 8.7×10^7 tons. It is the effective way that treats large quantities of straw, improves environmental sanitation and increases living standard in rural areas. It is assumed that 1 kg straw can produce 2 m^3 biogas and a household with 4 people only requires 5–6 m^3 biogas/day to meet its need of living. Table 6 is the investment and cost of straw gasification system for central biogas supply in China. As seen from Table 6, the more household of central biogas supply, the lower cost of the biogas. General speaking, the biogas cost is only about 0.11 RMB/m^3 in China presently.

3.4. Straw briquette

Straw briquette technology refers to press the straw in which moisture content is about 10% into all kinds of shaped fuel such as bar-formed, pellet-formed and block-formed under certain pressure (heat or unheated). Briquettes can be produced with a density of about 1000–1300 kg/m^3 from loose biomass of bulk density 10–20 kg/m^3, and the energy density is about 30000 kJ/kg, equivalent to medium coal. There is no dust and heave smoke discharged in the normal combustion condition, and concentrations of CO, CO_2, SO_2 and NO_x in the fume gas are much lower than the standard stipulated for coal burning boilers.

At present, the main types of straw briquette making machine developed in China are screw press and piston press (See Table 7). The mean down time is about 60–200 h for the wear of briquetting parts, and the productivity is relatively low, only 60–500 kg/h. Screw

Table 7
Main types of straw briquette making machine in China

Models	Types	Motor power (kW)	Heater power (kW)	Productivity (kg/h)	Power consumption (kWh/ton)	Density of briquette (kg/m^3)	Moisture content of raw material	Life of wearing parts (h)
B10–11	Screw	11	4	100–200	60–80	1100–1300	6–10%	~100
B10–15	Screw	15	4	130–150	60–80	1110–1300	6–10%	~100
JX-7.5	Screw	7.5	3	~110	100	1100–1300	~12%	<200
PB-I	Piston	7.5	—	60–100	65	900–1300	6–12%	~200
HPB	Hydraulic piston	18.5	4	300–500	71	800–1200	7–14%	>200

press is the dominant briquette making machine, the shaped fuel is bar-formed structure with a central hole and widely used in China for the advantage of stable operation, continuous production and easy combustion. Piston press technology is comparatively older than the screw press technology, and it consists of a flywheel that operates a piston, which presses straw through a tapered die where the briquette is formed. Nowadays, another type of briquetting machine is the hydraulic piston press. This is different from the mechanical piston press in that the energy to the piston is transmitted from an electric motor via a high pressure with single- or double-way hydraulic oil system. Because of the slower press cylinder compared with that of the mechanical machine, hydraulic piston press results in lower outputs, but it can tolerate higher moisture content of straw than the usually accepted 15% moisture content for mechanical piston presses. The third briquetting machine is roller press. By means of two or three rollers, straw is forced into a number of dies that arranged as holes bored on a thick steel disc or ring, pellet-formed fuel are produced, but it is not popular in China, often used as fodders in rural areas, partly as boiler fuels.

Straw briquette can help in expanding the use of straw in energy production, improve the volumetric calorific value of a fuel, reduce the cost of transport and better the fuel situation in rural areas. It is in the process of commercialization in China presently.

3.5. Others

3.5.1. Liquefaction

Biomass liquefaction includes biochemical conversion to produce ethanol and thermo–chemical conversion to produce bio-oil. The main technology of straw liquefaction is hydrolytic liquefaction and pyrolytic liquefaction. In fact, hydrolytic liquefaction is the process of producing ethanol, which is fermented by microorganism from materials of high starch content such as steamed and saccharified corn or potato. The ideal way is to get ethanol from agricultural and forestry residues which have high cellulose content, such as straw and fiber plants. Around 1990, China started the development and research on hydrolysis technology to produce ethanol, and has made some progress. Pyrolytic liquefaction process breaks down biomass such as straw and wood residue into charcoal and hydrocarbons under the condition of medium temperature (500–600 °C), high heating rate (10^4–10^5 °C/s) and very short of stay time (~2 s) [14]. A mixture of gas, liquid (bio-oil) and solid products is produced but the proportion of each component can be varied depending on the reaction conditions. The technology of straw liquefaction is on the stage of experiment in China presently.

3.5.2. Straw carbonization

Straw carbonization is the technology that puts briquette production of straw into furnace through pyrolysis (400 °C) in the condition of isolation of oxygen, then gets molding charcoal. It is calculated that 3 kg briquette production of straw may produce 1 kg molding charcoal, while the traditional way of producing charcoal is burning timbers, which 10 kg timbers can produce only 1 kg charcoal. The rigidity and density of molding charcoal are superior to the traditional charcoal, and the content of contamination in the molding charcoal is low. It is a high-grade fuel for civil use, and also can be substituted for some charcoal of melting nonferrous metal and alloy industry.

3.5.3. Bio-coal

Comminuted and dried to certain degree, straw and coal, mixed with some of absorbing sulfur agent in molding machine, can produce bio-coal at high pressure. When the bio-coal is burning, straw is burned out at first, as the ignition temperature of straw is below that of coal, then the pore-creating process makes bio-coal burn out fully. This combustion process is also of advantage to turn $CaSO_3$ into $CaSO_4$ in absorbing sulfur reaction, thus improving the rate of absorbing sulfur and decreasing the discharge of SO_x. On the other hand, the economy of bio-coal's process is increased without agglomerants, because the intensity of bio-coal is improved significantly by the adhesiveness of short fiber in straw.

Straw carbonization and bio-coal have extensive applications as energy and convenience for large-scale transportation and storage. But up to now, the key equipments cannot meet the needs of commercialization and large-scale promotion in China, because the equipments have high energy consumption, low reliability and inferior applicability, as well as the high cost of pre-processing.

4. Future R&D of straw in biomass energy in China

China is a big agricultural country, where straw is available in large quantities across the country. The main challenge to straw in biomass energy is how to develop and manage the adequate, affordable and reliable energy in a sustainable manner for fuel's social and economic development and environmental protection. Based on the real situation and technology, some aspects of research and development in China presently are as follows:

Firstly, considering the practical situation of China, the technology of improved stove and biogas must be investigated and popularized for meeting the needs of rural domestic energy, which enhances the combustion efficiency of improved stove and the aerogenesis efficiency of straw anaerobic digestion, develops comprehensive biogas eco-agricultural technology, and reduces the cutting quantity of firewood and the use of fossil energy resource, especially coal.

Secondly, popularize straw gasification systems for central gas supply in rich areas. Based on the commercialization and industrialization of low CV of straw gasification systems for central gas supply, high CV of straw gasification and relative technology should be researched, and improve the efficiency of gasification and the range of its applications.

Thirdly, based on the combustion of fossil fuels, straw direct combustion technology should be researched by developing the straw direct combustion boiler and relative equipments for large-scale utilization of straw on generating electricity and supplying heat.

Fourthly, according to the characteristic of straw, briquette making machine and bio-coal molding machine should be actively researched and developed in respect of decreasing the equipments energy consumption, enhancing the equipments reliability and applicability, and realizing the commercialization of briquette equipments.

Last, strengthen international cooperation and intercommunion, introduce foreign advanced technologies of straw utilization to quicken the steps of straw utilization in China, and establish the straw utilization and development structure with Chinese characteristic.

5. Conclusions

Straw resources and its utilization in biomass energy in China are discussed. In order to meet the need of rural energy and environmental protection, some technologies, including direct combustion, biogas, straw gasification and straw briquetting, have been already popularized and commercialized in China. But other technologies, such as liquefaction, straw carbonization and bio-coal, are developed slowly at present. Enhancing the combustion efficiency of improved stove, developing comprehensive biogas eco-agricultural technology, popularizing straw gasification systems for central gas supply, developing straw direct combustion and brituetting equipments, are the key technologies of large scale and efficient utilization of straw in biomass energy in the future in China.

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