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## Assessment of Straw Biomass Availability for Bioenergy Production in Heilongjiang Province, China

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**Abstract:** Since large-scale straw biomass-based biopower facilities have not started in China, scientific calculation methods for the total quantity of straw resources and the available quantity of resource are very limited. It is essential to explore a rational measurement and calculation method for stalk and straw resources. In this study, the available quantity of crop resources suitable for biomass power generation in Heilongjiang province was analyzed and the composition, regional distribution and straw-to-grain ratio of stalk and straw resources in this province were discussed. The abundant biomass resources in Heilongjiang Province offer great opportunities to develop sustainable and competitive bioenergy industry. The results will provide scientific data for large-scale development of bioenergy in the future.

**Key words:** Biomass, availability, bioenergy, assessment, straw

### INTRODUCTION

Energy is the basic driving force for the development and economic growth in the world. Due to the rapid growth of economy, energy demand and consumption continues to increase year by year. Currently, the growth rate of China's energy consumption has exceeded the rest countries, while the problems of energy security and environment have become increasingly severe (Mitchell, 2000). In order to achieve sustainable development, reduce dependence on fossil fuels and improve the ecological environment, China is vigorously developing and using renewable energy. Renewable energy is a widespread, inexhaustible and dependable supply of primary energy. Currently, biomass power generation has become the main form of bioenergy development in China due to the advantages of abundant resources and state policy for electric power subsidy. Promoting the development and utilization of bioenergy can improve China's energy structure, reduce emission of carbon dioxide and other greenhouse gases and alleviate the deteriorating ecological environment. Rational development and utilization of bioenergy plays an important role in improving the living environment of urban and rural people but also have significance in constructing an energy-saving society with sustainable development (Wu *et al.*, 2012).

China is a large agricultural country, with rich resource of crop stalks and straws and therefore it enjoys

unique advantage in developing straw biomass-based power industry. The national theoretic quantity of crop biomass resources was 820 million tonnes (moisture content 15%) (Liu and Shen, 2007). The estimated quantity of collected crop biomass was about 687 million tonnes, accounting for 83.8% of the theoretical quantity of resources, equivalent to 343.5 million tonnes of standard coal. From the regional distribution of straw resources, North China and the middle and lower reaches of the Yangtze River are the regions that are richest in straw resource, followed by Northeast China, Southwest China, Inner Mongolia and Xinjiang Autonomous Regions. The theoretical quantity of straw resources is low in Southern China and the Loess Plateau. The development of biopower industry can provide more job opportunities and improve the ecological conditions in rural areas.

However, a series of problems occurred in the process of development of straw power generation, such as insufficient supply of fuel straw and imbalanced storage and supply. The biomass for power plants is limited by the transport distance, types and resources of stalks and straws, etc.

Therefore, scientific planning should be made to determine the location and size of the biopower plants to avoid problems such as difficulty in access to resource, shrink of profit margin and rapid rise of fuel price. Collection and management of fuel is also an important issue for China to develop large-scale biomass power

generation. The governments should make reasonable straw purchasing and utilization policies and set up policies and mechanisms for the supply chain of straw biomass to promote the development of biomass industry. Since large-scale straw-based power generation has not started in China, scientific and accurate calculation methods to estimate the total available quantity of resource are lack. It is essential to explore a rational calculation method for stalk and straw resources.

In the study, the available quantity of crop resources suitable for biomass power generation in Heilongjiang province was analyzed and the composition, regional distribution and straw-to-grain ratio of stalk and straw resources in this province were discussed. Scientific data shall be provided by our research result for large-scale use and development of biomass energy in the future.

### STUDY AREA

Heilongjiang Province is located in the northeastern part of China, at longitude 121°11' - 135°05'E and 43°25' - 53°33' N. Its land area is about 473, 000 km<sup>2</sup>, accounting for 4.9% of the country's total land area. The arable land is 118, 300 km<sup>2</sup>, ranking first in the country. There are 12 provincial cities, including Harbin, Qiqihar, Mudanjiang, Jiamusi, Daqing, Heihe, Suihua, Yichun, Qitaihe, Jixi, Hegang, Shuangyashan and Daxing'anling Prefecture. Heilongjiang Province is the country's major agricultural province. Its fertile soil and good adaptability makes the place suitable for growing rice, corn, soybean, wheat, cotton, potatoes and oil crops. The total sown area of crops in 2010 reached 14.25 million hectares. The planting areas for major crops were: 2.975 million hectares for rice, 378, 000 hectares for wheat, 5.232 million hectares for corn, 14, 000 hectares for millet and 4.675 million hectares for legumes crops (Heilongjiang Statistics Bureau, 2011). Therefore, the utilization of crop straw resources in the province is promising.

### EVALUATION OF CROP STRAW BIOMASS IN HEILONGJIANG PROVINCE

**Theoretical quantity of resources:** The theoretical quantity of resources refers to the maximum quantity of a certain type of biomass, which is the basis for resource evaluation. The theoretical quantity is usually estimated by Eq. 1 with the known crop outputs and the straw-to-grain ratios of various crops, where P is the theoretical quantities of straw biomass in the study area (t/a), G<sub>i</sub> is the annual production of the ith crops (t/a), λ<sub>i</sub> is the straw to grain ratio of the ith crops, i is the serial number of different crops. The outputs of major farm products in various regions of Heilongjiang Province in 2010 are listed in Table 1:

$$P = \sum_{i=1}^n \lambda_i \cdot G_i \quad (1)$$

The straw-to-grain ratio λ<sub>i</sub> can be calculated by Eq. 2, where m<sub>i,s</sub> is the weight of the straw of the ith crops (kg), m<sub>i,g</sub> is the weight of the seed of the ith crops (kg), A<sub>i,s</sub> is the moisture content of the straw of the ith crops (%), A<sub>i,g</sub> is the moisture content of the seed of the ith crops (%), 15% is the moisture content of air-dried straw and 12.5% is the standard water impurity rate in China:

$$\lambda_i = \frac{m_{i,s}(1 - A_{i,s}\%)/(1 - 15\%)}{m_{i,g}(1 - A_{i,g}\%)/(1 - 12.5\%)} \quad (2)$$

The straw-to-grain ratio is very important for calculating the theoretical quantity of straws but it is very difficult to determine the acceptable value for each crop. The straw-to-grain ratio is also called “output factor” or “economic factor”. In the “Technical Codes for Survey and Evaluation of Crop Straw Resources” issued by (The Ministry of Agriculture, 2009) the straw-to-grain ratio is defined as the ratio of the straw output to the grain

Table 1: Major agricultural output in Heilongjiang Province, 2010 (Unit: tonne)

	Rice	Wheat	Corn	Foxtail millet	Sorghum	Beans	Potatoes	Oil crops	Bast fiber crops	Sugarbeet
Harbin	4,301,730		9,021,207	8,018	6,799	996,583	157,387	11,598	-	12,523
Qiqihar	1,339,964	18,765	6,248,741	9,810	56,206	1,811,971	391,562	87,756	14	1,260,233
Mudanjiang	353,763	3,303	1,560,207	195	447	588,404	38,933	60,949	630	100,683
Jiamusi	2,231,382	146	2,345,271	1,265	3,331	1,088,407	84,731	19,697	-	190,590
Daqing	588,525	748	4,161,752	13,640	129,114	124,683	37,593	30,844	285	69,260
Heihe	52,846	668,651	236,454		-	1,522,344	146,056	817	8,573	31,944
Suihua	2,459,004	9,407	9,941,024	14,034	9,413	812,607	207,989	5,679	6,982	350,649
Yichun	259,997	2,225	203,394		-	329,031	8,459	1,122	-	1,000
Qitaihe	136,138	150	420,599	92	250	156,527	8,144	7,794		768
Jixi	1,174,624	218	984,582	451	202	390,733	4,100	7,083		1,340
Hegang	372,155	116	330,045		62	80,300	3,143	602		2,586
Shuangyashan	360,055	379	1,602,756		-	295,756	9,529	18,790		101,381
Daxinganling		142,151	6,680	-	-	242,798	29,112	280	-	-

Statistical yearbook of Heilongjiang Province Heilongjiang Statistics Bureau (2011)

Table 2: Straw-to-grain ratios at different studies

Source	Straw to grain ratios										
	Rice	Wheat	Corn	Beans	Potatoes	Cotton	Peanut	Rapeseed	Sesame	Bast fiber crops	Sugarcane
Niu and Liu (1984) <sup>a</sup>	0.9	1.1	1.2	1.6	0.5	3.4 <sup>b</sup>	0.8 <sup>c</sup>	1.5	2.2		0.06
Xie <i>et al.</i> (2011a) and Xie <i>et al.</i> , 2011(b)	1.0	1.17	0.4	1.5 <sup>m</sup>	0.58 <sup>e</sup>	2.91 <sup>f</sup>	1.14	2.87	2.01	1.22/2.23 <sup>g</sup>	0.06 <sup>h</sup>
Ministry of Agriculture	0.623	1.336	2	1.5	0.5	3		2 <sup>i</sup>		2.5(2009) <sup>j</sup>	0.1
Cui <i>et al.</i> (2008) <sup>k</sup>	0.68	0.73	1.25			5.51		1.01			
Zhang and Zhu (1990) <sup>l</sup>	1.323	1.718	1.269	1.295 <sup>m</sup>		1.613	1.348	2.985	5.882	1.808 <sup>n</sup>	
Han <i>et al.</i> (2002)	0.97	1.03	1.37	1.71 <sup>m</sup>	0.61	3.0	1.52	3.0	0.64	1.7	0.25

<sup>a</sup>Dry weight with water content of 6-15%. <sup>b</sup>Value is the straw to seed cotton ratio. <sup>c</sup>value refers to the ratio between peanut vine and peanut in shell. <sup>d</sup>Value for straw by dry weight is obtained based on the average of multiple studies. <sup>e</sup>Value is derived from the average of sweet potato and potato. <sup>f</sup>Straw to grain ratio calculated is for raw cotton without considering cottonseed. <sup>g</sup>Ratio is 1.22 for Jute and 2.23 for Kenaf, respectively. <sup>h</sup>Value refers to the ratio between the sugarcane tops and sugarcane stem. <sup>i</sup>Water content of straw biomass is not indicated. <sup>j</sup>For oil crops. <sup>k</sup>Water content of straw biomass is 15%. <sup>l</sup>Value is calculated based on the harvest data from 300 agrometeorological experimental stations in China; Straw biomass is measured in dry weight, <sup>m</sup>Soybean, <sup>n</sup>For oil flax. <sup>o</sup>Water content of straw biomass is not indicated

output of such crop within a certain area. However, this concept does not apply to non-cereal crops and therefore is limited in application. Thereafter, Xie *et al.* (2010) referred to the concept of the residue factor and introduced a concept of “straw factor” that could suit straws of all crops.

Correct understanding straw-to-grain ratio and reasonable use are the keys to accurately calculate the theoretical resources. The straw-to-grain ratio can be greatly affected by moisture content. Therefore, it has to be clarified while choosing a straw-to-grain ratio. Currently, the straw-to-grain ratios used in most literatures are based on the moisture content of air-dried straw (10%-15%). Additionally, the straw-to-grain ratio for different types of crops should be accurately understood. For example, the straw-to-grain ratio of rice is the ratio of the straw to the yield of rice. The defined rice straw does not include rice husk. In the case of cotton, its straw-to-grain ratio is the ratio of cotton straw to seed cotton. Therefore, (Xie *et al.*, 2011a, Xie *et al.*, 2011b) proposed to distinguish stalk or straw from seeds for a specific kind of crop while determining the straw-to-grain ratio. Other factors may also affect the straw-to-grain ratio, such as breed, harvest mode, planting environment, planting region, etc. For example, the ratio for corn is recommended to be 2 by the “Outline of Survey on Rural Energy”, which is the same as the value in the “Evaluation on the Availability of Biomass Resources in China” that is jointly prepared by the State Ministry of Agriculture and the U.S. Department of Energy. However, (Cui *et al.*, 2008) determined the ratio to be 1.25 for corn in their study. The difference indicates that different scholars focus on different factors when they try to determine the ratio. The straw-to-grain ratios given by some literatures are summarized in Table 2.

Here, the straw-to-grain ratios are chosen according to the exiting selection methods for straw-to-grain ratio (Pan and Deng, 2007) and in consideration of the

geographic distribution of different crops in Heilongjiang province. They are: Rice 1.0, wheat 1.1, corn 2.0, foxtail millet 1.5, sorghum 3.0, beans 1.7, potatoes 1.0, oil crops 3.0, bast fiber crops 1.7 and sugarbeet 0.1. Now, the theoretical quantities of straws in Heilongjiang Province can be computed using Eq. 1 with known parameters (production of crops and straw to grain ratios).

Distribution of crop straw resources is basically the same as the distribution of crop yields in the province. Crop straw resources are mainly located in Harbin, Suihua and Qiqihar. The theoretical quantities of straws in the three regions account for 62.5% of the total quantity in the province, followed by Daqing and Jiamusi (17.6%), Mudanjiang, Shuangyashan, Jixi and Heihe (15.8%), Hegang, Yichun, Qitaihe and Daxing'anling (4.1%).

**Collectable quantity of resources:** The collectable quantity of resources is the quantity of biomass that can be collected through existing collection methods in a region, which is usually less than the theoretical quantity of resources. The collectable quantity of agricultural biomass resources are affected by many factors, such as harvest mode, harvest time, climatic factors, techniques and collection radius, which can be calculated according to Eq. 3, where  $P_c$  is the collectable quantities of straw biomass in the study area (t),  $\eta_{i,1}$  is the collectable coefficient of the  $i$ th crops:

$$P_c = \sum_i^n \eta_{i,1} \cdot (\lambda_i \cdot G_i) \quad (3)$$

Collection coefficient can be estimated through the stubble height of crops, weight percentage of biomass in leaves and loss rate in collection and transport. However, the collectability and utilization coefficients for the three major crops (rice, wheat and corn) shall be divided into two groups: mechanical harvest and manual harvest. Under mechanical harvest mode, the stubble heights for

Table 3: Agricultural straw biomass output and collectable amount in Heilongjiang Province, 2010 (Unit: 10, 000 tonnes)

Crops	Rice	Wheat	Corn	Foxtail millet	Sorghum	Beans	Potatoes	Oil crops	Bast fiber
Agricultural output	1843.9	92.50	2324.4	4.10	17.80	601.90	126.2	27.50	2.20
Straw output	1843.9	101.75	4648.8	6.15	53.40	1023.23	126.2	82.50	3.74
Collection coefficient	0.8	0.65	0.9	0.80	0.80	0.88	0.8	0.88	0.87
Collectable amount	1475.1	66.10	4183.9	4.92	42.72	900.40	101.0	72.60	3.30

Statistical Yearbook of Heilongjiang Province, Heilongjiang Statistics Bureau (2011)

Table 4: Usable amount of agricultural straw biomass and standard coal equivalent in Heilongjiang Province (2010) (Unit: 10, 000 tonnes)

Crops	Rice	Wheat	Corn	Foxtail millet	Sorghum	Beans	Potatoes	Oil crops	Bast fiber
Collectable amount	1475.100	66.1	4183.900	9.420	42.720	900.400	101.000	72.600	3.300
Usable amount	590.000	26.4	1673.600	3.800	17.100	360.200	40.400	29.100	1.300
Coal equivalent coefficient	0.429	0.5	0.529	0.486	0.486	0.543	0.486	0.529	0.543
Standard coal equivalent	253.100	13.2	885.300	1.850	8.310	195.600	19.600	15.400	0.710

rice, wheat and corn are 16, 25 and 15 cm, respectively. Under manual harvest mode, the stubble heights for rice, wheat and corn are 7 cm, 6 cm and 6 cm, respectively. The weighted proportions of two harvest modes are considered during calculating the coefficient. The mean collectability coefficients for the three crops are 0.80, 0.65 and 0.90 (Cai *et al.*, 2011) respectively. In summary, the output of crop straw and the collectable quantity of Heilongjiang Province are shown in Table 3.

**Available quantity of resources:** Compared to the calculation of other quantity of resources, the evaluation of the available quantity of resources will be affected by more factors and become more complex. However, accurate evaluation on the available quantity of resources is of greater and more immediate practical significance in planning biopower plants or industry. The practical available quantity is lower than the collectable quantity of resources. Estimate can be made by using Eq. 4, where  $p_e$  is the quantity of the available biomass in the study area (t),  $\eta_{i,2}$  is the utilization coefficient of the  $i$ th crop. The utilization coefficient  $\eta_{i,2}$  is calculated according to Eq. 5, where  $j$  is the utilization modes except energy,  $j = 1, 2, \dots, m$ ;  $\mu_{ij}$  is the proportion of the  $j$ th utilization mode for the  $i$ th crop:

$$P_e = \sum_i \eta_{i,2} \cdot \eta_{i,1} \cdot (\lambda_i \cdot G_i) \quad (4)$$

$$\eta_{i,2} = 1 - \sum_j \mu_{i,j} \quad (5)$$

The proportions of crop straw used for a specific application are obtained through field survey. Previous study showed that in Heilongjiang Province, the proportions of straw biomass utilization are rural domestic energy 25%, use as animal feeds 18%, straw that returns to the farmland 15%, industrial use 0.2%, straw used fungus culture 2.5% and the utilization as energy 40%, respectively (Li *et al.*, 2001). The available quantity of crop straw in Heilongjiang Province is presented in Table 4 with utilization factor of 40%.

**Standard coal equivalent of available resources:** The standard coal equivalent for biomass energy can be obtained by multiplying the calculated available quantity of biomass by the standard coal equivalent coefficient Eq. 6, where  $P_m$  is the standard coal equivalent for available straw biomass in the study area (t),  $\eta_{i,3}$  is the standard coal equivalent coefficient for the  $i$ th crop straw. The standard coal equivalent for various crop straw resources in Heilongjiang Province is shown in Table 4.

$$P_m = \sum_i \eta_{i,3} \cdot \eta_{i,2} \cdot \eta_{i,1} \cdot (\lambda_i \cdot G_i) \quad (6)$$

## CONCLUSION

This study provides an assessment of crop biomass quantities potentially available for biopower generation in Heilongjiang Province, China. Based on the calculations, the standard coal equivalent is 13.93 million tonnes in Heilongjiang Province in 2010. It is noted that the biomass would also serve as an alternative fuel source in the coal-fired power facilities besides biopower plants. The potentially available biomass varies by crop variety and crop yield but is also dependent on the minimal amount of residue needed to avoid soil erosion and the technical capability of harvesting equipment to collect the residues. The results show that the utilization of crop straw resources as energy is very promising in Heilongjiang Province. Future research can be conducted to assess the costs involved in collecting, transporting and storing the biomass directly to the biomass enterprise.

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