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Renewable and Sustainable Energy Reviews 13 (2009) 479–485

RENEWABLE & SUSTAINABLE ENERGY REVIEWS

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Utilization of carbon-negative biofuels from low-input high-diversity grassland biomass for energy in China

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Received 20 September 2007; accepted 9 October 2007

Abstract

This paper analyzes utilization of carbon-negative biofuels from low-input high-diversity grassland biomass on degraded lands (LIHD) for energy including energy equivalent to green house gases (GHG) capture and storage. The results show that the energy output of LIHD biomass on degraded soil is nearly equal to that of ethanol from conventional corn grain on fertile soil. It has also been shown that LIHD biofuel is far more economical than the conventional biofuels such as corn ethanol or soybean biodiesel.

China is a large agriculturally developing country, with its rural area largely populated and vast land degraded. It is in this respect that we analyzed the utilization of LIHD. The potential of using energy from LIHD biomass on degraded lands in China is estimated. The results show that the potential energy production of LIHD biomass reaches 6350971.32 TJ year^{-1}, accounting for about 15% of China's energy consumption in 2002.

Keywords: LIHD; GHG; Soybean biodiesel

Contents

1. Introduction

In recent years, rapid development of global economy and increase in population and living standards have been posing great pressure in natural resources and the environment. Fossil fuels are being exhausted at a very fast rate. Moreover, utilization of fossil fuels together with net deforestation [1] has induced considerable climate change in warming the atmosphere by releasing GHG which may produce many negative effects including receding of glaciers, rise in sea level, loss of biodiversity, extinction of animals, and loss of productive forests [1], acidification of oceans, killing of heat waves, and retreat of butterflies up mountainsides worldwide [2]. These effects have compromised the ability of many countries to develop sustainably. Climate change had drawn the world's highest attention with the release of the Stern Review [3]. The Stern Review pointed out that the damage induced by climate change could rise to 20% of GDP or more if effective acts are not taken [3,4]. The GHG capture and storage technology has

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1364-0321/$ – see front matter
doi:10.1016/j.rser.2007.10.003

recently been developed [5], which can slow global warming which is slowing economic development in many countries. In fact, the core of the current problem is how to coordinate the developments of energy, society, economy and the environment. Therefore, there is an urgency to find alternative energy supply technologies with a great mount of renewable and clean energy resource to take the challenge of energy needs and slow the buildup of pollutant gases and GHG.

Biomass is an abundant and renewable energy source. It has remained the primary source of energy for more than 50% of the world's population, and accounts for 14% of the world's energy consumption [6], which is second to fossil fuels. Biomass is a low-carbon fuel containing less sulfur and ash but more hydrogen than coal. Its gaseous or liquid production is clean [7]. Biofuel from biomass becomes a sink for GHG because biomass is low in carbon and absorbs CO_2 in its production. Biomass therefore is likely to be an attractive option for reducing GHG emission.

The biomass for conventional biofuel production includes monoculture crops grown on fertile soils (such as corn, soybeans, oilseed rape, switchgrass, sugarcane, willow, and hybrid poplar) and waste biomass (such as straw, corn stover, waste wood and animal manures). However, the conventional biofuel production on fertile land competes with food production, increases pollution from fertilizers and pesticides, and threatens biodiversity on natural lands [8]. The removal of biofuel, which removes nutrients from the soil, has the potential to cause land degradation in many areas especially in infertile areas. For example, the cost of cultivation including purchasing of fertilizers, pesticides, etc. is occasionally over the cost of rice production in some rural regions [9].

Since Tilman reported utilization of carbon-negative biofuels from low-input high-diversity (LIHD) grassland biomass on degraded land (LIHD) for energy [8] more researchers are emerging to carry out work in this area.

China is the largest developing country agriculturally, with its rural area largely populated. However, the arable land is just 13.55% of China's land with vast land degraded [10].

Li and Hu [7] have estimated the potential of using afforestation for sustainable biomass production for energy in China. Zeng et al. [6] reported the present utilized technologies of straw in biomass energy and estimated the potential of the technology in China. Wang and Feng [11] discussed the supply of biomass energy resources mainly being crop-straw in the rural area and the effect of the discharge of noxious gases from consumption of biofuels. With these works in mind, we compare in this work energy output from LIHD biomass biofuels with conventional biofuels including energy equivalent to GHG capture and storage and report the potential of utilization of carbon-negative biofuels from LIHD biomass on degraded lands in China.

2. Utilization of carbon-negative biofuels from low-input high-diversity grassland biomass for energy in China

The carbon-negative biofuels from LIHD biomass is a high-diversity biomass grown with low inputs on agriculturally degraded land. Compared with conventional biofuel biomass, LIHD biomass has many other merits [8]. Except for the low energy input and high output the merits can be enumerated as follows:

(1) They will avoid competing with food production on fertile soils.
(2) They will avoid the biodiversity loss due to the plantation of conventional monoculture biofuels, and lower plant diseases and insect pests in high-diversity plant mixtures, thus decreasing pollution from large amount of pesticides.
(3) They will decrease pollution from large amount of fertilizers. For example, avoid the input of nitrogen fertilizers because legume is used to fix atmospheric nitrogen.
(4) Compared with conventional biofuels being net carbon sources, LIHD biofuel belongs to carbon-negative biofuels which are absorbers of more atmospheric CO_2 than GHG released in biofuel production and combustion. This results in the reduction in atmospheric CO_2.
(5) LIHD also provide other ecosystem services, including renewal of soil fertility, cleaner ground and surface waters, and conducive wildlife habitat.
(6) The productivity of high-diversity grass is certain. This determines a certain, continuous supply of biomass, avoiding the variable supplies of forest and agricultural residues.

3. Economical analysis

Tilman et al. [8] compared the figures of energy input and output for two food-based biofuels on fertile soils and three LIHD biofuels on degraded soils. It was found that the LIHD biomass with low input but high output is more economical than corn biomass in producing energy. In addition, LIHD biofuel is carbon-negative biofuels. This will indirectly obtain more economic benefit from dismissing capture and storage of GHG. In order to show the effect of GHG in the environment, energy used to dispose of GHG should be added into energy output in our calculation.

Fig. 1 reports the comparisons of energy input and output for these six biofuels under different conditions. Included in the original diagram is degraded soil, degraded soil including energy equivalent to GHG capture and storage in a new diagram. Also shown in the original diagram is fertile soil, fertile soil including energy equivalent to GHG capture and storage in a new diagram. The prairie yields of LIHD biomass on fertile soil and degrade soil are estimated as $6000\ \mathrm{kg\ ha^{-1}\ year^{-1}}$ and $3682\ \mathrm{kg\ ha^{-1}\ year^{-1}}$, respectively [8]. Net storage costs is based on cases including depleted gas reservoir, depleted oil reservoir, deep saline aquifer, enhanced oil recovery, enhanced coalbed methane recovery, ocean pipeline, and ocean tanker. The costs of capture and seven storages are respectively estimated by Bock et al. [5] to range from 86, 81, 77, 15, 41, 89 to 143 USD $\mathrm{ton^{-1}}$. In this work we use the average cost estimated for the seven storages at 76 USD $\mathrm{ton^{-1}}$. Energy equivalent to GHG capture and storage

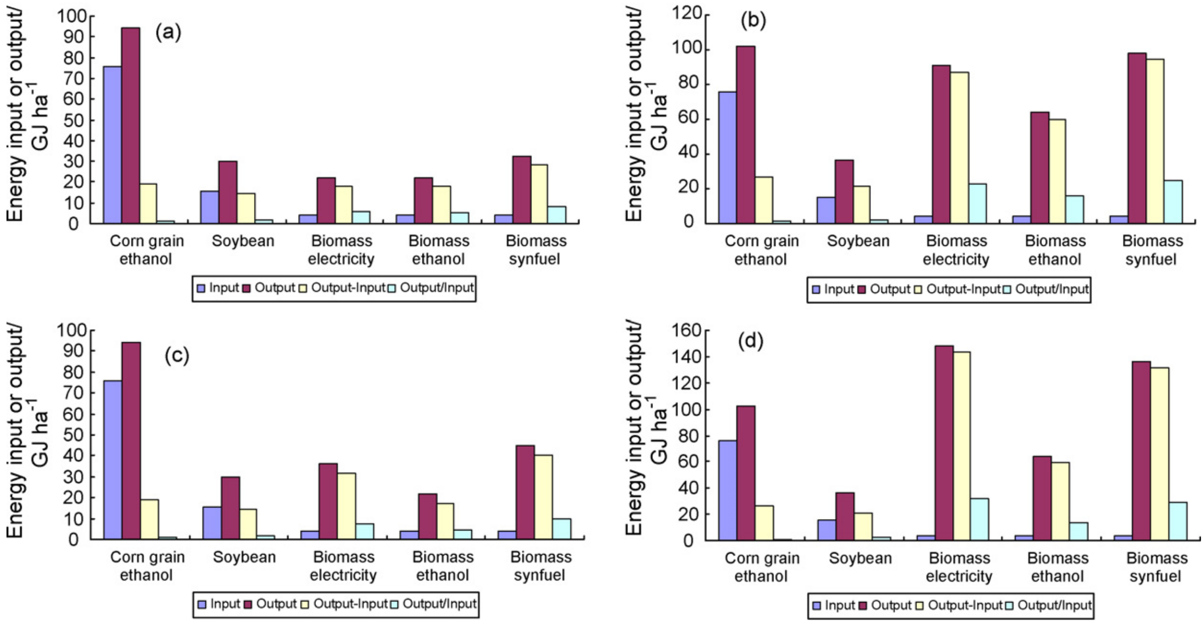

Fig. 1. Comparison of energy input and output for the six biofuels: (a) original diagram on degraded soil; (b) new diagram on degraded soil including energy equivalent to GHG capture and storage; (c) original diagram on fertile soil; (d) new diagram on fertile soil including energy equivalent to GHG capture and storage.

Table 1
Net GHG reduction from biofuel production including from the conventional biomass and LIHD biomass [8]

	Production on fertile soil		Production on degraded soil			Production on fertile soil		
Biofuel	Corn grain ethanol	Soybean biodiesel	LIHD biomass electricity	LIHD biomass ethanol	LIHD biomass synfuel	LIHD biomass electricity	LIHD biomass ethanol	LIHD biomass synfuel
Net GHG reduction (kg CO_2 equivalent ha^{-1})	1134	995.1	10088	6164	9626	16438.9	6164	13354.3

is calculated according to the equivalent cost to the electricity from conventional coal combustion whose price used here is 0.04 USD kW h^{-1} [12].

Due to high CO_2 soil or root sequestration on degraded soil, and low release of GHG from biomass, net GHG reduction from LIHD biomass biofuel production as compared with coal combustion is far larger than the conventional corn biomass, as shown in Table 1.

As shown in Fig. 1a, net energy balance (NEB) ratio of biofuel from LIHD biomass on degrade soil is several times larger than that of corn grain ethanol and soybean biodiesel. It can also be seen in Fig. 1a and b that the energy output of LIHD biofuel is drastically increased when the energy equivalent to GHG capture and storage is added into the energy output, while those of corn and soybean are increased only a little due to less net reduction of GHG emission. Energy output for biomass *synfuel* reaches 98.3 GJ ha^{-1} which approaches that for corn grain ethanol which is 102.3 GJ ha^{-1}.

Also as shown in Fig. 1c, energy output of LIHD biofuel on fertile soil is also lower than that of the corn ethanol. However, the NEB ratio remains constant.

As shown in Fig. 1d, energy output of LIHD biofuel on fertile soil is much more than that of the corn besides the NEB ratio and the NEB.

4. Estimate of potential energy production in China using LHID biofuels

4.1. Land distribution

From the 1996 data from China's land survey office, the untilled land area of China is 245.09 million ha, which is 25.8% of the surveyed land area of 950.68 million ha.

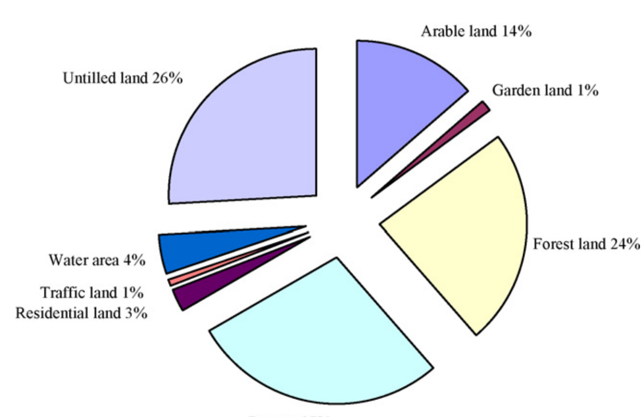

Fig. 2. Utilized status of lands in China.

Table 2
Land resources from China's first widespread investigation of land resources in 1996 [13]

Regions	Total area (million ha)	Waste grassland (million ha)	Salina land (million ha)	Wetland (million ha)	Sand land (million ha)	Barren soil land (million ha)	Rocky land (million ha)	Ribbing land (million ha)	Others (million ha)	Total untilled area (million ha)	1st present[a] (%)	2nd present[b] (%)
North of China	151.86	6.04	0.48	1.35	7.42	0.26	6.75	1.01	1.13	24.45	10.00	16.10
Beijing	1.64	0.13	0.00	0.00	0.00	0.01	0.06	0.01	0.00	0.22	0.10	13.20
Tianjin	1.19	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.00	5.69
Hebei	18.84	2.51	0.13	0.01	0.03	0.02	0.93	0.28	0.13	4.05	1.70	21.47
Shanxi	15.67	2.65	0.06	0.00	0.01	0.06	0.84	0.64	0.81	5.06	2.10	32.30
Inner Mongolia	114.51	0.72	0.28	1.33	7.38	0.18	4.92	0.08	0.18	15.06	6.10	13.15
Northeast of China	79.18	3.78	0.43	2.13	0.06	0.02	0.11	0.08	0.38	6.99	2.80	8.82
Liaoning	14.81	1.12	0.02	0.02	0.01	0.01	0.07	0.08	0.18	1.51	0.60	10.18
Jinli	19.11	0.44	0.39	0.14	0.04	0.01	0.01	0.01	0.09	1.13	0.40	5.90
Heilongjiang	45.26	2.22	0.02	1.97	0.01	0.00	0.03	0.00	0.11	4.35	1.80	9.62
East of China	80.84	2.42	0.26	0.01	0.05	0.06	0.54	1.79	0.21	5.34	2.20	6.60
Shanghai	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
Jiangsu	10.67	0.05	0.02	0.00	0.00	0.00	0.02	0.03	0.02	0.15	0.10	1.39
Zhejiang	10.54	0.34	0.01	0.00	0.00	0.01	0.07	0.24	0.03	0.70	0.30	6.62
Anhui	14.01	0.21	0.00	0.00	0.01	0.00	0.07	0.42	0.04	0.75	0.30	5.38
Fujian	12.41	0.54	0.00	0.00	0.00	0.01	0.11	0.28	0.01	0.96	0.40	7.72
Jiangxi	16.69	0.67	0.00	0.00	0.02	0.03	0.10	0.24	0.05	1.13	0.40	6.75
Shandong	15.71	0.59	0.24	0.00	0.01	0.00	0.17	0.58	0.06	1.65	0.70	10.54
Central south of China	101.59	5.92	0.01	0.02	0.06	0.20	3.47	2.42	0.31	12.41	5.10	12.22
Henan	16.55	0.88	0.01	0.01	0.04	0.07	0.44	0.24	0.19	1.87	0.80	11.27
Hubei	18.59	1.31	0.00	0.00	0.00	0.05	0.24	0.51	0.00	2.12	0.90	11.38
Hunan	21.19	0.60	0.00	0.00	0.00	0.05	0.40	0.93	0.05	2.04	0.80	9.61
Guangdong	17.98	0.57	0.00	0.00	0.01	0.02	0.09	0.25	0.03	0.97	0.40	5.41
Guangxi	23.76	2.30	0.00	0.00	0.00	0.01	2.30	0.49	0.04	5.16	2.10	21.71
Hainan	3.54	0.25	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.26	0.10	7.49
Southwest of China	232.77	17.18	0.55	0.14	0.46	0.53	22.88	5.73	6.86	54.33	22.20	23.34
Chongqing	8.23	0.34	0.00	0.00	0.00	0.02	0.23	0.91	0.01	1.52	0.60	18.43
Sichuan	48.41	0.73	0.00	0.08	0.23	0.05	2.50	1.98	0.20	5.77	2.40	11.92
Guizhou	17.62	0.55	0.00	0.00	0.00	0.01	1.04	1.10	0.00	2.70	1.10	15.32
Yunnan	38.32	4.53	0.00	0.00	0.00	0.22	0.85	1.66	0.03	7.30	3.00	19.05
Tibet	120.21	11.02	0.55	0.06	0.22	0.23	18.27	0.08	6.62	37.05	15.10	30.82
Northwest of China	304.42	13.92	8.44	0.65	42.45	2.86	69.78	1.43	2.04	141.57	57.70	46.50
Shanxi	20.58	0.75	0.03	0.00	0.13	0.03	0.10	0.13	0.00	1.17	0.50	5.69
Gansu	40.41	1.78	0.41	0.04	1.82	0.38	10.55	1.07	0.07	16.11	6.60	39.88
Qinghai	71.75	1.08	3.91	0.29	6.14	1.57	10.52	0.12	1.21	24.84	10.10	34.62
Ningxia	5.20	0.08	0.07	0.00	0.15	0.00	0.10	0.08	0.33	0.82	0.30	15.80
Sinkiang	166.49	10.23	4.02	0.32	34.21	0.88	48.51	0.03	0.42	98.62	40.20	59.23
Total	950.68	49.25	10.17	4.30	50.49	3.93	103.53	12.47	10.94	245.09	100.00	

[a] Percent of untilled area to total untilled area.
[b] Percent of untilled area to survey land.

Untilled land is second to pasture land which is 27% in the classifications of 1st-type land use [13], as shown in Fig. 2.

Table 2 presents the data of untilled land area in all the regions in China. In the table, the untilled land includes waste grassland, barren soil land, wetland, saline land, sand land, ribbing land, rocky land, and other lands. Amongst these types of lands, waste grassland, barren soil land is the best available for LIHD grassland development, wetland and saline land is the second best, sand land is hard to be utilized, and rocky land is never available for LIHD grassland development.

According to all the waste grassland and the barren soil land, 90% of the wetland and the saline land, and 10% of ribbing land and other lands, and 4% [13] of sand land being available for LIHD development, the land area available for LIHD grassland development can be calculated to be 70.57 million ha as shown in Table 2, forming 29% of total untilled land, which does not reach the value 100 million ha or more as evaluated by Wang [14] and Shi [15] because the sand land of large area which is always covered by sands is very difficult for planting biomass. As shown in Table 2, the potential biomass focuses on the Northwest, Southwest, and North of China which will be the main places of biomass plantations. The potential production of LIHD biomass is therefore 6350.97 GJ $year^{-1}$ a figure based on biomass productivity of 90 GJ ha^{-1} $year^{-1}$ by neglecting performance difference among all the types of available degraded lands [8].

4.2. Potential energy production

The potential energy production is estimated based on original diagram by neglecting the energy equivalent to GHG capture and storage and its percent in the land area in each region. This information is shown in Fig. 3.

Table 3 presents a comparison of China's energy consumption in 2002 and potential bioenergy from available degraded lands per year. As shown in Table 3 and Fig. 3, the total energy production that can be reached is 63509.71 TJ $year^{-1}$, which accounts for about 15% of 43440310.87 TJ $year^{-1}$ of China's energy consumption in 2002. This shows that LIHD biomass can support the development of China as part of other energy resources. In Table 3, a majority of regions of China belong to the regions of negative surplus of biomass except three regions with net surplus of biomass including Tibet, Sinkiang, and Qinghai. This distribution results from soil performance and economic development of all the regions. In the regions including East, Central south, North and Northeast of China, there are fertile soils, convenient traffic, good economy and dense population, thus require fully developing the available lands and also in order to take care of the large capacity of energy needs. In the regions including Southwest and Northwest of China, most of the land is agriculturally degraded, very little traffic exist, there is bad weather, undeveloped or lagging economy, and sparse population. This makes large amount of land untilled. The regions

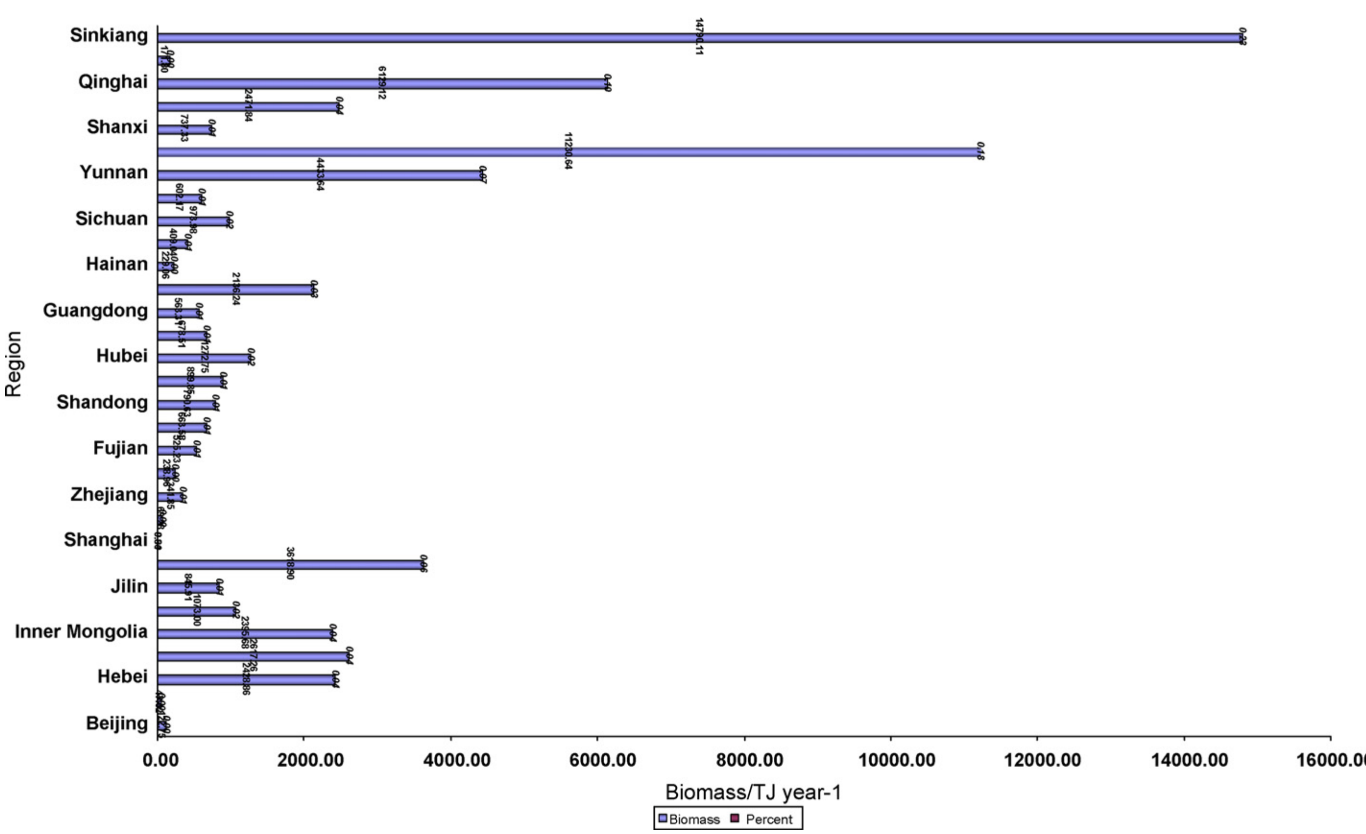

Fig. 3. Potential biomass in available untilled land resources in China.

Table 3
Comparison of energy consumption in 2002 and potential bioenergy per year from China Energy Statistical Yearbook 2000–2002 [16]

Regions	Difference (TJ $year^{-1}$)	Potential bioenergy (TJ $year^{-1}$)	Energy consumption in 2002 (TJ $year^{-1}$)
North of China	−8913807.97	761216.94	9675024.91
Beijing	−1307446.67	12274.56	1319721.23
Tianjin	−880913.41	4762.26	885675.67
Hebei	−3153278.27	242886.42	3396164.69
Shanxi	−2475310.82	261725.94	2737036.76
Inner Mongolia	−1096858.80	239567.76	1336426.56
Northeast	−5587918.96	553781.70	6141700.66
Liaoning	−2999012.36	107300.16	3106312.52
Jinli	−1191168.65	84591.18	1275759.83
Heilongjiang	−1397737.94	361890.36	1759628.30
East	−13091560.45	263033.64	13354594.09
Shanghai	−1793251.04	81.00	1793332.04
Jiangsu	−2809238.90	6928.38	2816167.28
Zhejiang	−2130473.92	34185.42	2164659.34
Anhui	−1534096.30	23895.72	1557992.02
Fujian	−970312.32	52522.92	1022835.24
Jiangxi	−695346.98	66357.54	761704.52
Shandong	−3158840.99	79062.66	3237903.65
Central south	−9743578.13	577972.44	10321550.57
Henan	−2431348.13	89984.70	2521332.83
Hubei	−1840143.89	127275.30	1967419.19
Hunan[a]	−1410717.60	67850.82	1478568.42
Guangdong	−3271547.16	56330.82	3327877.98
Guangxi	−660328.27	213624.36	873952.63
Hainan	−129493.08	22906.44	152399.52
Southwest	−3856508.25	1764947.34	5621455.59
Chongqing	−898111.40	40904.10	939015.50
Sichuan	−2103602.40	97398.36	2201000.76
Guizhou	−1249832.88	60216.84	1310049.72
Yunnan	−711062.60	443363.76	1154426.36
Tibet[b]	1078252.96	1123064.28	44811.32
Northwest	−1151369.46	2430019.26	3581388.72
Shanxi	−1014458.15	73733.04	1088191.19
Gansu	−637319.63	247183.74	884503.37
Qinghai	314267.62	612912.06	298644.44
Ningxia[c]	−231348.71	17179.74	248528.45
Sinkiang	417489.41	1479010.68	1061521.27
Total[d]	−37089339.55	6350971.32	43440310.87

[a] The value predicted according to recent data.
[b] The value estimated according to the sum of fossil fuel consumption and bioenergy consumption in rural area [17].
[c] The value predicted according to recent data.
[d] The fact the total of energy consumption from China Energy Statistical Yearbook 2000–2002 is less than the sum of energy consumption in all the regions results from the calculation of all the regions according to different thermal equivalent conversion factor.

therefore need only small amount of energy. Therefore, net surplus of biomass in the three regions including Tibet, Sinkiang, and Qinghai in Southwest and Northwest of China can be developed to be LIHD biofuel base, and large amount of surplus of biofuel can be converted into energy products such as electricity, ethanol and hydrogen and transported to the adjacent regions of negative biomass surplus for utilization.

Using LIHD biomass combustion for electricity, about 1.42 billion tonnes net GHG emission per year is reduced for potential biomass biofuel on degraded lands in China, and about 108.2 billion USD per year can be saved for capturing and storage of GHG.

5. Conclusion

Utilization of LIHD biomass on degraded lands for energy including energy equivalent to GHG capture and storage is analyzed in this paper. The results show that the energy output of LIHD biomass on degraded soil is nearly equal to that of ethanol from conventional corn grain on fertile soil. LIHD biofuel is far more economical than the conventional biofuels such as corn ethanol or soybean biodiesel.

In the current state of global warming, China a large agriculturally developing country with vast degraded land needs a great mount of renewable energy to meet its rapidly growing economy and sustainable development. One of the solutions to China's energy problems lie in use of renewable energy sources for her economy and the use of LIHD is inevitable.

The estimated results of the potential energy from LIHD biomass on degraded lands in China show that the potential energy production of LIHD biomass reaches 6350971.32 TJ $year^{-1}$, accounting for about 15% of China's energy consumption in 2002.

In order to meet China's energy need and to fulfill some of the environmental protection requirements, some biofuel technologies, including direct combustion, hydroxylation ethanol and gasification, have been already investigated and commercialized in China. LIHD biomass is available for utilization using the advanced technologies. In order to develop the untilled land fully, developing the planting technology of LIHD biomass on each type of available untilled lands in any region and enhancing the conversion efficiency of improved biomass are the key to large scale and efficient utilization of LIHD biomass energy in the future for China.

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