B-51 Studies on the Evaluation of Estimation of Anthropogenic Sources and Sinks of Greenhouse Gases

B-51.1.6(formerB-51.2) Estimation of Carbon Dioxide Fixation by Forestry Biomass and Biomass Energy

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Abstract Potentials of land area available for energy plantation and biomass supply in the world were estimated. Also biomass-to-energy conversion processes was evaluated and reduction amounts of CO2 through these processes and then total system was estimated.

The land area available for biomass plantation was estimated to be 1677 Mha, and the amount of the supply of biomass energy was 495EJ/y at medium biomass productivity (considering no land-use competition with food supply). When taking into consideration of competition with food supply, reduction of the biomass energy supply was under 15-20% of that with no competition except the case of high nutrient intake-low cereal productivity.

Reductions in CO2 emission through four biomass energy conversion processes;combustion, gasification, pyrolysis and fermentation; were 0.14-0.53, 0.21-0.66, 0.28, and 0.19-0.34 t-C/t-biomass, respectively. The gasification process was the most effective. Total amount of CO2 reduction in global scale through these biomass energy conversion processes were 0.8-14.1 Gt-C/y, which showed reduction of CO2 proposed by COP3 (Kyoto protocol)can be attained . Among biomass power generation system, contribution by plantation was the largest(80% of total emission).

These results obtained suggest forestry biomass and biomass energy can largely contribute to energy supply and mitigation of CO2.

Key words: Forestry biomass, Biomass energy plantation, Land use, Biomass-to-energy conversion, CO2 mitigation

1. Introduction

Biomass that is renewable and fixes CO2 in atmosphere is considered as one of the most favorable options for reducing CO2 emission and preventing climatic changes. It has been advocated biomass energy will largely introduced in a quite near future in IPCC Report and COP3 Kyoto Protocol, and it is required to conduct research on the available biomass and the energy introduction system and its effect on CO2 mitigation.

2. Research Objectives

The purpose of this study is to estimate possibility of supply and application of biomass energy and also to investigate an effect on CO2 mitigation by using biomass energy. We estimate potentials of land area available for energy plantation and biomass supply in the world in several cases. Also we evaluate biomass-to-energy conversion processes and estimate reduction amounts of CO2 through these processes and then total system.

3. Method

1) Estimation of the energy supply potential of forestry biomass

The amount of biomass energy was calculated using the following formula:

Amount of energy supplied (EJ) = Potential reforestation area (Mha)

X productivity of wood(t-B/ha/y) x heating value of the wood (GJ/t-B) x 10^{-3} .....(1)

The potential reforestation area and productivity(yield) of forestry biomass(wood) for the whole world was the sum calculated by adding all the individual country values. The productivity(yield) of wood was classified into high, medium and low level in 3 different climate zones as seen in Table 1, and each country was assigned under a certain climate zone. The heating value used was 20 GJ/t-B.

When competition with food supply is not taken into consideration, potential land area is calculated as the following based on the FAO Report and the FAO Assessment.

Land area for forestry biomass plantation area=

Area of "forest and other wooded land" – Area of "forest"= Area of "other wooded land"

When competition with food supply is taken into consideration, land area is calculated according to the formula:

R=C x Q x 365/(E x 10^{3} x P) .....(2)

R: the necessary farming area R (Mha) in the year 2100.

C: the population in the year 2100.(cap.10.9 billion, from the World Bank forecast data)

Q: the amount of cereal caloric value consumed per cap (kcal/cap/day, converting all the food into cereals, 6000kcal/da/cap ;average of developing countries; low intake, 10000 kcal/day/cap ;average of developed countries; high intake). **E**:the amount of caloric value of cereals (kcal/kg, 2,666kcal/kg), **P**: cereal yield (t/ha/y. 2.6 t/ha/y at low level, 6.0 t/ha/y at high level, 4.3 t/ha/y at medium level)

When "Area of farmland(arable, permanent crops, and permanent pasture) – R(necessary farming area) results in negative(-) (case of lack of farmland), in order to maintain the population, the area of lacking farmland is allocated to "other wooded land" within the same country.

2) Evaluation of technology to convert biomass into energy

Four energy conversion technologies, that is, 1)combustion/power generation, 2)gasification /power generation, 3)pyrolytic liquefaction, and 4)ethanol fermentation were investigated. As for combustion/generation, more than 50 commercial plants(25-75MW scale) are in operation in the

United States and North Europe. As for gasification, coal gasification plant has already been commercialized in a large scale and there are demonstration plants of 160-350 t/d scale that uses biomass. In pyrolytic liquefaction, biomass is rapidly heated at about 500 ℃ to produce liquid fuel (bio-oil). The pyrolytic liquefaction is still in the smaller scale than the above two processes, and the largest scale of its test plants is 15 t/d. As for ethanol fermentation, four million ethanol (from sugarcane) automobiles are running in Brazil. Although ethanol fermentation used woody biomass has not been commercialized, there is a test plant of 1 t/d.

In the calculation, 1)biomass in combustion/power generation and gasification/power generation was replaced to coal in coal thermal power generation, 2)bio-oil was used as fuel of a thermoelectric power plant in place of coal, and 3)ethanol was used as fuel for cars in place of gasoline. The amount of carbon replacement R_G (t-C/t-B) by using biomass in place of fossil fuel was calculated according to the following formulas.

(a)combustion and gasification/ power generations:

$$\mathbf{R_G = Q_B \times \theta_C \times \eta_B / \eta_C} \quad .....(3)$$

Q_B: heating value of biomass, 20 (GJ/t-B); θ_C: carbon emission from coal, 0.025 (t-C/GJ); η_B: power generation efficiency of biomass (%); and η_C: power generation efficiency of coal= 37 %.

(b) pyrolitic liquefaction/power generation:

$$\mathbf{R_G = Q_P \times \theta_C \times Y_P} \quad .....(4)$$

Q_P : heating value of bio-oil (GJ/t-oil); Y_P: Yield of bio-oil (t-oil/t-B).

Available data on the bio-oil/power generation efficiency are few to determine η_B. Calculation was made here as $\eta_B = \eta_C$ in order to estimate the largest substituted quantity by means of biomass.

(c) gasoline substituted with ethanol fermentation:

$$\mathbf{R_G = Y_B \times \theta_G \times R_{EG}} \quad .....(5)$$

Y_B : yield of ethanol (t-ethanol/t-B); θ_G : carbon emission of gasoline, 0.00072 (t-C/L-gasoline); R_{EG}: ethanol/gasoline conversion factor, 1.1×10^{-3} (volume of gasoline necessary to get the same output of gasoline engine as that of ethanol engine with).

We investigated the power generation efficiency of biomass for the combustion and gasification generations, the yield and heating value of oil for the pyrolytic liquefaction, and the yield of ethanol for the ethanol fermentation. Other parameters are of values accepted broadly and generally

3) Estimation of net carbon replacement

It was assumed that biomass was used for power generation in place of coal. The amount of carbon replacement by using biomass in place of coal was referred to R_G. The biomass power generation system was composed of five processes: (a) plantation of biomass from field preparation to harvest (The amounts of carbon emission (kg-C/t-B) from the processes "a" were referred to R_p), (b) collection of harvested biomass (R_{CB}), (c) transportation of biomass to power generation plant (R_{TB}), (d) pretreatment of biomass for power generation(R_{PT}), and (e)biomass power generation. The amount of net carbon replacement R_N was calculated as follows:

$$\mathbf{R_N=R_G-(R_P+R_{CB}+R_{TB}+R_{PT})} \quad .....(6)$$

R_G, R_{CB}, and R_{TB} were calculated using the following formulas.

$$\mathbf{R_G= Q_B \; x \; \theta_C \; x \; \eta_B/\eta_C} \quad .....(7)$$

$\eta_B= \alpha C_A{}^{\beta}$; and C_A : capacity of power generation plant (MW)

$$\mathbf{R_{CB}=C_{CB} \; x \; D_a/W_a} \quad .....(8)$$

C_{CB}: carbon emission from transport medium for biomass collection (kg-C/km);

D_a : the distance for biomass collection (km); W_a : the weight of biomass harvested in one year (t-B).

$$\mathbf{R_{TB}=C_{TB} \; x \; D_{TB}/L_T} \quad .....(9)$$

C_{TB} : carbon emission from transport medium (kg-C/km); D_{TB} :the distance to power generation plant (km); L_T : the load capacity of the medium(t-B).

Table 2 shows the parameters used in the estimation of net carbon replacement.

4. Result and discussion

1) Estimation of the energy supply potential of forestry biomass

The result of the estimated area of potential reforestation without taking competition with food supply into account is shown in Fig. 1. The total potential area in the world for reforestation was found to be 1677 Mha. This value was much greater than the area value 850-500 Mha reported in IPCC report which was carried out in a similar manner using the top down method.

Figure 2 shows the top ten countries showing high potential for reforestation. At the top comes Canada with 206 Mha, The former USSR comes second with 187 Mha, and Brazil third with 106 Mha. The top three countries take up 30% of the potential reforestation area, and the top ten countries take up 966 Mha, which accounts for 60% of the global total.

Table 3 shows the estimated energy supply when there is no competition with food supply. The global total energy supply was shown to be 881 EJ/y at high yield, 495 EJ/y at medium yield, and 252 EJ/y at low yield. In the second IPCC report, the supply target is 300 EJ, more than 1.5 times the IPCC's reported energy supply values can be guaranteed at the middle level of productivity.

Table 4 shows the estimated energy supply and potential reforestation area when taking competition with food supply into consideration. With high intake and low cereal yield, the area for potential reforestation is 0; which means that the all population cannot be maintained despite all potential as well as "other wood land" throughout the whole world being used for food production.

The smallest values are taken when there is high intake and medium cereal yield alongside potential reforestation area and energy supply, but compared to when there is no competition, the reduction in area is contained at 15-20 %, and energy at around 15-20%. This shows that the effect of competition with food supply is small.

2) Evaluation of technology to convert biomass into energy

Efficiency of combustion/power generation was in the range of 10-39 % and that of gasification/power generation was 14-49%. In the pyrolytic liquefaction, oil yield was in the range of 0.53-0.76 (t-oil/t-B) and heating value or 15.8-17.2 (GJ/t-oil). In the ethanol fermentation, yield of ethanol was in the range of 0.24-0.43 (t-ethanol/t-B).

Shown in Table 5 is the result for R_G calculated from investigated result. Reduction amount of CO_2 was the largest when gasification/power generation was adopted. It was also found that making use of biomass in the combustion and gasification generations for the replacement of electric power was more effective than the ethanol fermentation to be replaced with gasoline.

3) Estimation of net carbon replacement

The effect of C_A is shown in Fig 3. R_N increased monotonically with increase in C_A.

In order to evaluate the transport distance, critical D_{TB} was defined as the distance when $R_N=0$. The relationship between critical D_{TB} and C_A is shown in Fig 4. This figure shows that ship was suitable for long distance transportation. The longest distance for transportation of biomass is 20000km, which is a half of the circumference of the earth; thus, using imported biomass in Japan over 0.8MW plant capacity could reduce CO2 emission from Japan.

The effect of the carbon emission processes to R_N is listed in Table 6. Total carbon emission from the system was 10 % of R_G. Plantation process contributed mainly to total carbon emission (80% of total). R_{CB} and R_{TB} showed small contribution to total carbon emission, 5%.

The result of sensitivity analysis of parameters is indicated in Tables 7 and 8. These tables show little effect of Y, C_T, C_{CB} , L_{TB} , L_{CB}, and S on R_N.

Global carbon replacement was calculated using reforestation area without competition with food supply obtained. The table shows that replacement of 5-8 (Gt-C/y) can be globally achieved by using a small power generation plant such as 1MW; therefore, biomass energy would be much effective to reduce global CO_2 emission.

In case of using imported biomass in Japan, 7-12 Mha of plantation area in foreign countries is necessary to achieve the Japan's target of carbon reduction, 19 Mt-C/y. The area is equivalent to 20-30% of the total land area of Japan, and it would be possible to obtain the area out of Japan. Therefore, using imported biomass in Japan would be much effective to reduce CO_2 emission from Japan.

Table 1 Productivity of biomass(t-B/ha/y)

	Climate zone		
	Tropical	Temperate	Frigid
High	30	25	20
Medium	19	13	8
Low	10	6	4

(yield of wood)

Table 2 Parameters used for the estimation of net carbon replacement

Carbon emission form plantation process, R_P (kg-C/t-B)	32.04
Carbon emission from transportation process, R_{PT} (kg-C/t-B)	6.89
Capacity of Power generation plant, C_A (MW)	25
Standing peirod, S (y)	10
Load capacity for collection, L_{CB} (t-B)	8
Carbon emission from collection medium, C_{CB} (kg-C/km)	1.05
Load capacity for transportation, L_{TB} (t-B)	15 (truck) 400 (train) 2500 (ship)
Carbon emission from transport medium, C_{TB} (kg-C/km)	0.91 (truck) 20.0 (train) 25.2 (ship)
Distance to power generation plant, D_{TB} (km)	30
α	0.179 (steam) 0.264 (gasification)
β	0.126 (steam) 0.086 (gasification)
Biomas yield, Y (t-B/ha/y)	10
Heating value of biomass, Q_B, (GJ/t-B)	20
Carbon emission factor of coal, θ_C (kg-C/GJ)	27.99
Efficiency of coal firing power generation, η_C(-)	0.37

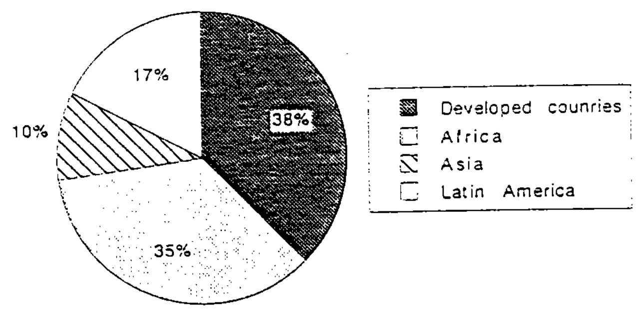

Fig.1 Estimated area of potential reforestration, no competiton with food supply (total: 1677Mha)

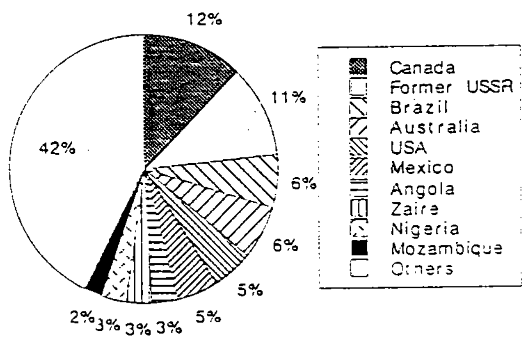

Fig. 2 Top 10 countries of high potentail reforestration, no competition with food supply

Table 3 Estimated energy supply, no competition with food supply (EJ/y)

	Yield of Biomass		
	High	Medium	Low
Developed countries	276	124	60
Africa	348	217	113
Asia	93	56	29
Latin America	165	98	50
Total	881	495	252

Table 4 Estimated energy supply, competition with food suplly

Cereal caloric value intake	Cereal Yield	Biomss energy supply(EJ/Y) Biomass yield			Area(Mha)
		High	Medium	Low	
Higy	High	780	432	219	1506
	Medium	715	392	197	1349
	Low	0	0	0	0
Low	High	844	472	239	1616
	Medium	814	453	229	1564
	Low	719	394	199	1401
(no competition)		881	495	252	1677

Table 5 Carbon replacement, R_G

Table 5 (a) Combustion power generation

η_B (%)	R_G (t-C/t-B)
39	0.53
25	0.34
10	0.14

Table 5 (b) Gasification power generation

η_B (%)	R_G (t-C/t-B)
49	0.66
31	0.42
14	0.21

Table 5 (c) Pyrolytic liquefaction

Q_P (GJ/t-oil)	YP(t-oil/t-B)	R_G (t-C/t-B)
16.3	0.69	0.28

Table 5 (d) Ethanol fermentation

Y_E(t-ethanol/t-B)	R_G (t-C/t-B)
0.43	0.34
0.34	0.27
0.24	0.19

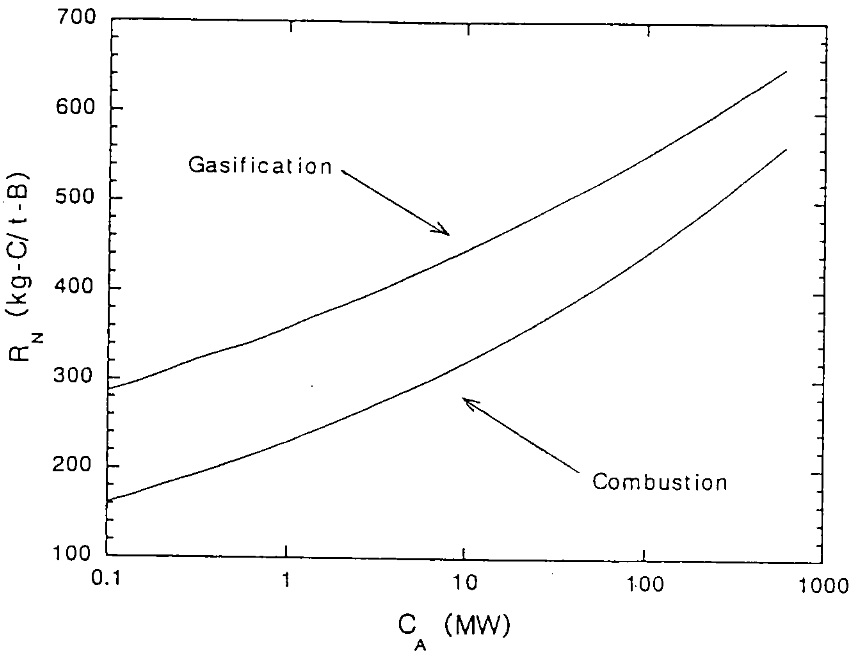

Fig. 3 Effect of C_A on R_N

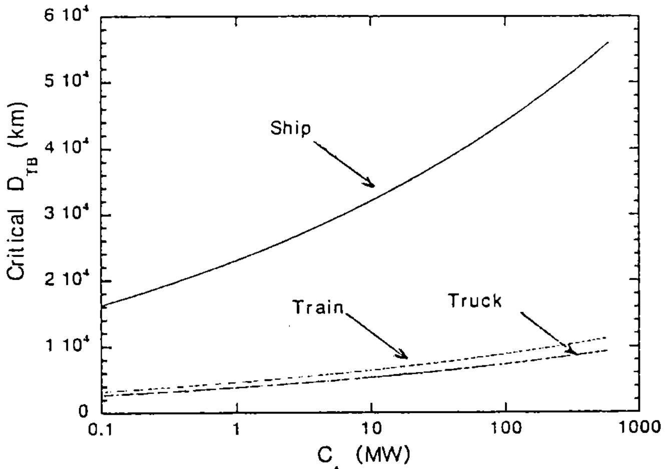

Fig.4 (a) Critical D_{TB} (combusiton)

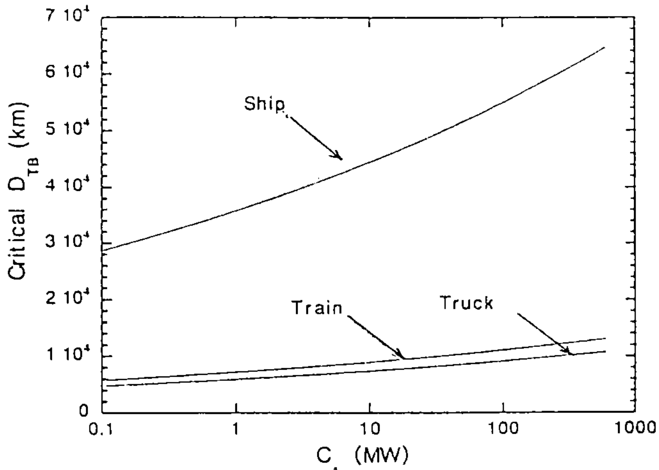

Fig.4 (b) Critical D_{TB} (gasification)

Table 6 Effect of carbon emission process to R_N (kg-C/t-B)

	R_G	R_P	R_{PT}	R_{CB}	R_{TB}	R_T	R_N
Combusiton	406.28	32.04	6.89	0.60	1.82	41.35	364.93
Gasification	526.81	32.04	6.89	0.53	1.82	41.28	485.53

Table 7 Effect of biomass yield on R_N

	Biomass Yield (t-B/ha/y)	RN(kg-C/t-B) C_A (MW)		
		1	25	100
Combustion	5	229.9	364.7	441.5
	10	229.9	364.9	442.0
	20	229.9	365.1	442.3
Gasification	5	358.3	485.3	551.4
	10	358.5	485.5	551.8
	20	358.6	485.7	552.1

Table 8 Effect of parameters on spesific R_N

	Combustion					Gasification				
	Multiplic lication factor					Multiplic lication factor				
	0.25	0.5	1	1.5	2	0.25	0.5	1	1.5	2
C_{TB}	1.004	1.002	1.000	0.998	0.995	1.003	1.002	1.000	0.998	0.996
C_{CB}	1.001	1.001	1.000	0.999	0.998	1.001	1.001	1.000	0.999	0.999
L_{TB}	0.985	0.995	1.000	1.002	1.002	0.989	0.996	1.000	1.001	1.002
L_{CB}	0.995	0.998	1.000	1.001	1.001	0.997	0.999	1.000	1.000	1.001
S	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Spesific RN is defined as the ratio of R_N by using modified parameter to R_N by using unmodified parameters