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Economic and Environmental Evaluation of Biomass-fired Power Generation in Japan (September 2006)

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Abstract *- In this study, biomass-fired power generation in Japan was evaluated from the viewpoints of economics and the effects on the environment. Feedstock cost, plant capacity, and the efficiency of electricity generation were estimated with regard to the collection distance. Accordingly, the cost of electricity generation and the effect on* CO_2 *mitigation were obtained as functions of the collection distance. From the economic viewpoint, a collection distance of approximately 50 km was considered realistic. However, since forest biomass is expensive, a policy that excludes the feedstock cost and includes tax reduction would be required. On the other hand, from the environmental viewpoint, the effect on* CO_2 *mitigation was maximum when the collection distance was approximately 50 km; therefore, this was estimated as the optimum collection distance. In conclusion, a biomass-fired power plant is expected to contribute toward mitigating global warming.*

Keywords - Biomass-fired power generation, economic and environmental evaluation, CO_2 mitigation, LCA

1. INTRODUCTION

Global warming has become a serious problem because of an increase in greenhouse gases such as CO_2. Utilization of biomass as an energy resource is required for a sustainable society since biomass is carbon-neutral. Considering this, woody biomass-fired power plants present attractive options, and some plants have already been constructed in Japan. However, woody biomass is more expensive than fossil fuels such as coal because it is used not only as power plant feedstock but also for building materials. Therefore, the economics of this process is an important issue, and an economical power generation system is required. Generally, because an increase in plant capacity leads to a decrease in heat loss, the efficiency of power generation increases. Besides, the cost of construction of a power plant unit is lowered, thus reducing the cost of power generation. However, a considerable amount of feedstock has to be supplied to increase the plant capacity. Consequently, the costs of feedstock and its collection would increase. In order to form an economic estimate of the process, the plant capacity and the costs involved in the purchase and collection of feedstock should be considered.

On the other hand, since woody biomass is carbon-neutral, power generation using it is expected to lead to mitigation of CO_2 emission. However, even in this case, CO_2 is emitted during the collection of feedstock and the construction of the plant. Besides, low efficiency of power generation reduces the mitigation of CO_2. Tahara et al. indicated a trade-off between CO_2 mitigation that is related to plant capacity and CO_2 emission during feedstock collection for biomass power generation with sustainable afforestation [1]. In other words, although an increase in afforestation area leads to an increase in feedstock and a subsequent improvement in the efficiency of power generation, CO_2 emission increases during the collection and transport of feedstock. From the viewpoint of reducing environmental load, an optimum design condition in which the collection, transport, and plant capacity are considered should be investigated.

In this study, the economics and environmental effect of a woody biomass-fired power plant were evaluated. Factors such as the amount of feedstock and plant capacity were estimated with regard to the distance from the site of collection to the plant. The effect of these factors on the cost of electricity and CO_2 mitigation was studied. The economic constraints in the construction of biomass-fired power plants were discussed, and the optimum operating condition was evaluated.

2. EVALUATION METHOD

In this study, woody biomass was used as feedstock. Woody biomass can be classified into forest biomass and waste biomass. Forest biomass includes thinning wood and forest residue that can be used as an energy resource, and waste biomass includes sawmill residue and construction waste wood. The distance from the site of woody-biomass collection to the plant and the amount of collection were related to the emission density. The amount of collection enables the estimation of plant capacity and the efficiency of power generation. The cost of construction and the running cost are calculated from the plant capacity. These costs were correlated with the plant capacity. Therefore,

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the unit cost of power generation can be estimated from combination of all these factors.

On the other hand, CO_2 was emitted during the collection of feedstock and the construction of the plant. Collection involves the harvest and the transport of feedstock. Thinning is performed not for the feedstock for power generation but for the growth of the remaining trees in a stand. Therefore, CO_2 emission during thinning should not be taken into account in this study. The CO_2 emitted during collection includes only that emitted during the transport. Similarly, for sawmill residue and construction waste wood, only the CO_2 emitted during transport is taken into account. On the other hand, it can be considered that the electricity produced from biomass mitigates CO_2 emission.

3. ECONOMIC STUDY

Feedstock

i) Amount of biomass emission

Thinning wood, forest residue, sawmill residue, and construction waste wood was considered as feedstock for power generation; their properties are listed in table 1.

Although their moisture contents vary under different conditions such as changing atmospheric humidity, the typical values of their moisture content were used in this study. The heating value, which depends on how dry the fuel is, increases with a decrease in the moisture content.

In Japan, many investigations concerning the amount of biomass emission have been performed. The amount of biomass that can be used as an energy resource has been reported in table 2 [2–4]. It was assumed that the biomass was uniformly emitted in Japan and the emission density was estimated from the land area of Japan. The estimated emission density correlates the amount of collected biomass to the collection distance. For example, it is estimated that over a distance of 50 km, 39600 t/y of thinning wood, 41600 t/y of forest residue, 41000 t/y of sawmill residue, and 97200 t/y of construction waste wood are collected.

Table 1. Properties of Woody Biomass

	Moisture content	Low heating value kJ/kg
Thinning wood	0.5	7955.3
Forest residue	0.4	10048.8
Sawmill residue	0.2	14654.5
Construction waste wood	0.2	14654.5

Table 2. Emission Amount and Emission Density of Woody Biomass

	Emission amount t/y^2	Emission density t/km^2y
Thinning wood	1870000	5.05
Forest residue	1960000	5.30
Sawmill residue	1930000	5.22
Construction waste wood	4580000	12.40

ii) Log cost

The log cost of Japanese cedar, which is a common type of wood in Japan, was used in this study. The log costs of thinning wood and forest residue are shown in table 3 [4]. The Japanese cedar is valued at ¥ 5900 per ton without log production. The cost of log production involving cutting, pruning, and bucking and the cost of personnel amounts to ¥ 13500 per ton. The transport of wood to the lumberyard costs ¥ 3100 per ton. The log cost can be obtained by summing up these costs. On the other hand, because forest residue is waste, no cost is attached to it. However, we recognized that cutting and transport of forest residue as well as thinning wood would require expenditure. The final total cost amounted to ¥ 16600 per ton.

We assumed that the cost of sawmill residue was ¥ 3000 per ton. The cost of the construction waste wood was obtained by assessing the charge for a waste treatment; this was estimated to be ¥ 1000 per ton.

Table 3. Log Costs of Thinning Wood and Forest Residue

	Tree value Yen per ton	Log production cost Yen per ton	Transport cost Yen per ton	Total cost Yen per ton
Thinning wood	5900	13500	3100	22500
Forest residue	-	13500	3100	16600

iii) Transport cost

The forest biomass that was stocked in the lumberyard, the sawmill residue and the construction waste wood have to be transported to the power plant. In this case, the cost of transporting the construction waste wood is borne by the person who emitted it. Therefore, it was assumed that transport of the construction waste wood was without charge. It was assumed that 10 T trucks were used for the transport. The relationship between the transport distance and the transport cost is shown Fig. 1 [3].

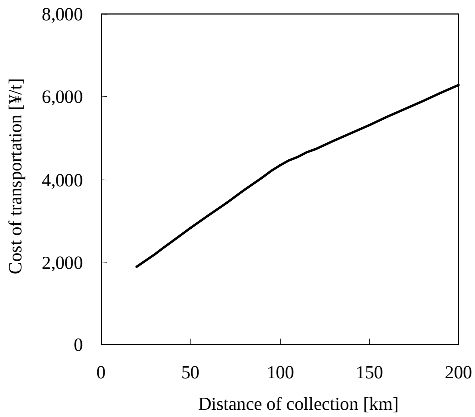

Fig. 1. Relationship between collection distance and transport cost.

iv) Feedstock cost

The final feedstock costs of the thinning wood, the forest residue and sawmill residue comprise the log cost and the transport cost. However, it was assumed that of the construction waste wood was independent of distance and that it was ¥1000 per ton.

Power Plant

i) Plant capacity and efficiency of electricity generation

It has been reported that the efficiency of electricity generation is related to plant capacity in that it increases with the increase in plant capacity. In this study, it was assumed that plants with a capacity of 1000 kW have an efficiency of 10%, those with a capacity of 10000 kW, 20%; and those with a capacity of 100000 kW, 30%; these values were estimated by taking into account previous studies [2, 4].

ii) Cost of construction

Although the total cost of construction of a power plant increases with higher plant capacity, the unit cost of construction decreases. Considering a previous study [4], it was assumed that a plant of 1000 kW capacity is constructed at the cost of ¥ 1000,000 per kilowatt; a plant of 10000 kW capacity, at the cost of ¥ 400000 per kilowatt; and a plant of 40000 kW capacity, at the cost of ¥ 200000 per kilowatt. We assumed that the rate of interest for construction was 4% and that the lifetime for the depreciation was 10 years. No subsidy for the construction was taken account of.

iii) Running cost

The running cost of the power plant mainly comprises the maintenance cost, personnel cost, and the cost of ash treatment. It is assumed that the maintenance cost was 3% of the construction cost.

In plants with a capacity of 1000 kW to 10000 kW, the following equation for the relationship between the capacity and the staff number has been reported [3].

$$\text{Staff number} = 0.000778 \times \text{plant capacity} + 4.222$$

In this equation, the figures after the decimal fractions should be rounded up. In plants with a capacity greater than 10000 kW, it was assumed that the staff number was 12. The personnel cost for a staff was assumed to be ¥ 8000000 per year.

Woody biomass contains ash that accounts for 1% of biomass weight. The ash was emitted by biomass combustion; the cost of ash treatment was ¥ 10000 per ton.

Electricity cost

The electricity cost can be estimated from the data that were assumed in the preceding section. In this study, we considered the cases in which the thinning wood and forest residue, the sawmill residue, the construction residue, and whole biomass were used. The relationship between the collection distance, the plant capacity, and the efficiency of electricity generation is shown in Fig. 2. The relationship between the collection distance and the electricity cost is shown in Fig. 3. In all the cases, the electricity cost rapidly decreases with increasing distance for short distances. However, for long distances, the effect of distance on the electricity cost decreases with an increase in distance. In plants using forest biomass, although an increase in the capacity is observed, the electricity cost increases even for long distances due to the expensive feedstock. When whole biomass was used, the capacity and efficiency of the plant increased and the electricity cost was reduced even for short collection distances. The system that can collect a considerable amount of feedstock from a smaller area is efficient.

On the other hand, we considered the exclusion of the feedstock cost, barring the transport cost. In this case, the electricity cost remarkably decreased; the cost was ¥ 7.6 per kilowatt for a distance of 50 km and ¥ 5.3 per kilowatt for a distance of 80 km. From an economic point of view, we believe that the exclusion of the feedstock cost and the reduction in tax would be effective for the popularization of biomass-fired power generation.

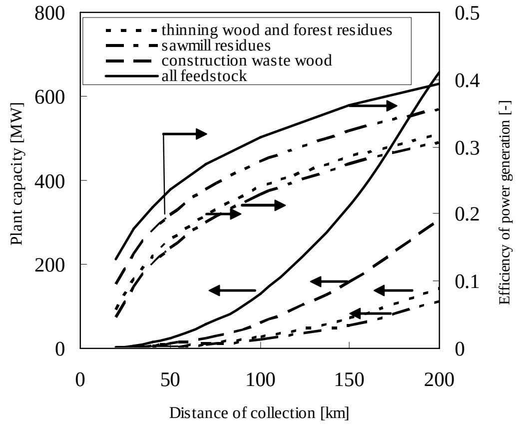

Fig. 2. Relationship between collection distance, plant capacity, and the efficiency of electricity generation.

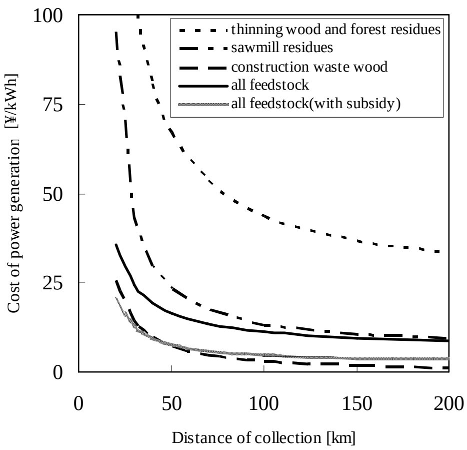

Fig. 3. Relationship between collection distance and electricity cost.

4. ENVIRONMENATL LOAD

Environmental load was studied from the viewpoint of CO_2 mitigation. In this case, CO_2 emissions during the collection of feedstock and construction of power plants and CO_2 mitigation by the electricity generated from biomass were considered.

CO_2 Emission during Feedstock Collection

Thinning is performed not for the feedstock for power generation but for the growth of the remaining trees in a stand. Therefore, CO_2 emission during thinning should not be taken into account in this study. The CO_2 emission during the formation of forest residue, sawmill residue, and construction waste wood should be similarly excluded. CO_2 emission during the transport of feedstock was taken into account; the mileage of a 10 T truck was estimated to be 3 km/l of diesel oil. Diesel oil emits 2.644 kg of CO_2 per liter.

CO_2 Emission during the Construction of Power Plants

For the construction of a coal-fired power plant with a capacity of 1000 MW, Uchiyama and Yamamoto [7] estimated CO_2 emission by utilizing the materials, electricity and other energy sources. Tahara et al. [1, 5] and Hanaoka et al. [6] estimated that for a power plant which had different capacity from the coal-fired power plant by 0.7th power rule. In this study, CO_2 emitted during the construction of a power plant was also estimated by a method used by them. Table 4 shows the amount of material required and the CO_2 emission in the coal-fired power plant with a capacity of 1000 MW. In this study, the lifetime of the plant was assumed to be 30 years. Accordingly, the annual CO_2 emission was estimated.

Table 4. Amount of CO_2 Emission for Coal-fired Power Plant with a Capacity of 1000 MW

Materials and energy	Amount of materials and energy [t or MWh] [7]	CO_2 emission factor [kg-CO_2/kg or kg-CO_2/kWh]	CO_2 emission [t-CO_2]
Steel	62200	1.180	73367
Aluminum	624	2.040	1270
Concrete	178320	0.099	17722
Coal	14339	2.880	34175
Oil	709	3.220	2279
Electricity	12700	0.382	4852
Total			133665

CO_2 Mitigation by Electricity Generated from Biomass

Biomass-fired power generation can be used as an alternative to power generation by the existing methods that involve CO_2 emission; therefore, the amount of CO_2 mitigated by using biomass-fired power plants also includes that emitted by the existing power plants. The CO_2 emission factor for electricity generation is 0.382 kg-CO_2/kWh.

Effect of Biomass-fired Power Generation on CO_2 Mitigation

Figure 4 shows the relationship between the collection distance and the extent of CO_2 mitigation. The relationship between the plant capacity and the extent of CO_2 mitigation is shown in Fig. 5. In case of a very short collection distance, the effect on CO_2 mitigation was less due to the small amount of feedstock and lower efficiency of electricity generation. On the other hand, an increase in the amount of feedstock improves the efficiency. However, in cases of long collection distances, CO_2 emission increases due to transport. Accordingly, the effect on CO_2 mitigation is reduced. From the viewpoint of CO_2 mitigation, we estimated an optimum collection distance and a plant capacity of approximately 50 km and 10 MW, respectively.

On the other hand, with regard to the effect of the type of feedstock on CO_2 mitigation, it was believed that feedstock that can be collected over a shorter distance and large amounts has a greater effect. A maximum amount of feedstock should be collected within a distance of approximately 50 km from the plant, and whole biomass should be used.

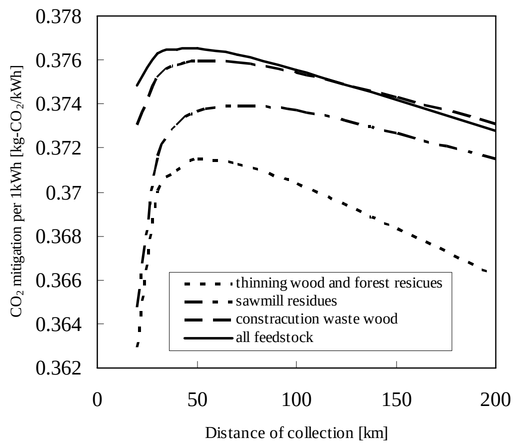

Fig.4. Relationship between collection distance and extent of CO_2 mitigation.

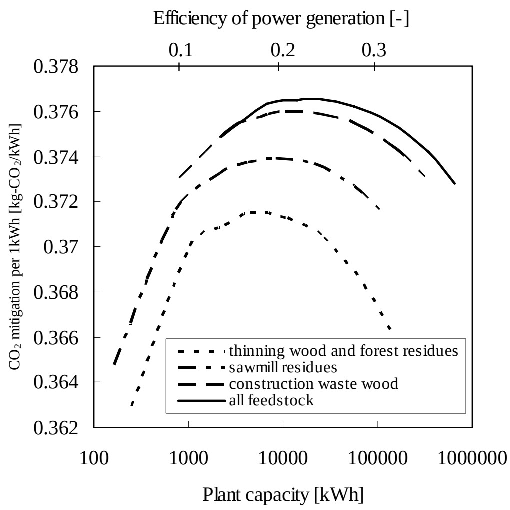

Fig.5. Relationship between plant capacity and extent of CO_2 mitigation.

It was confirmed that the effect of power generation on CO_2 mitigation increased when whole biomass such as forest biomass and waste biomass were used. However, forest biomass is expensive and raises the electricity cost. This would be disadvantageous for the economy. Therefore, a policy involving a reduction in tax and/or the exclusion of the forest biomass cost in the computation of tax would be required if the forest biomass is to be used in order to optimize the effect on CO_2 mitigation. For example, environmental tax such as carbon tax has already been introduced in some countries. Generally, renewable energy resources are tax-free although fossil fuels are taxed. It should be possible to use the tax revenue to reduce the cost of expensive renewable energy resources such as forest biomass.

In addition, purchase of the electricity generated from renewable energy resources must be ensured. For example, in Germany, Erneuerbare Energien Gesetz (EEG) was enforced, and the electricity generated from renewable energy resources was traded at a premium. Further, in Japan, renewables portfolio standard (RPS) was enforced, and it was made obligatory for renewable energy to be used in excess of a specified amount.

Finally, these policies would help popularize biomass-fired power generation. Biomass-fired power plants are expected to contribute toward mitigating global warming.

5. CONCLUSIONS

Biomass-fired power generation in Japan was evaluated from the viewpoints of economics and the effect on the environment. In order to improve the efficiency of power generation and to reduce the electricity cost, not only waste biomass but also forest biomass should be utilized. However, since forest biomass is expensive, a policy that excludes the cost of feedstock and includes tax reduction would be required. Because the increase in transport distance increases the CO_2 emission, an optimum collection distance of approximately 50 km was estimated to be adequate. Finally, biomass-fired power plants are expected to contribute toward mitigating global warming.

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