CO_2 Mitigation by Biomass-fired Power Generation in Japan

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ABSTRACT

CO_2 mitigation was estimated based on life-cycle CO_2 analysis when woody biomass was burnt for electricity generation instead of coal. Taking the procurement system of woody biomass into account, the construction of about 150 biomass-fired plants having a capacity of 5 MW each can be considered feasible in Japan. About 30 600 tons of CO_2 a year can be mitigated by a 5 MW biomass-fired power plant; therefore, the total CO_2 mitigation by 150 biomass-fired power plants was estimated to be about 4.58 million tons of CO_2 a year. The CO_2 mitigation estimated in the present work is equivalent to 7.3% of the CO_2 mitigation required in the Kyoto Protocol target. Accordingly, the biomass-fired power plants proposed are considered one of the potential countermeasures to prevent global warming.

1. INTRODUCTION

In Japan, biomass and bioenergy have been attracting attention from the viewpoints of the promotion of sustainable society, revitalization of rural communities, creation of new industries, and prevention of global warming by replacing fossil fuels with biomass. In cooperation with six government organizations (the Cabinet Office; the Ministry of Agriculture, Forestry and Fishery; the Ministry of Economy, Trade and Industry; the Ministry of Education, Culture, Sports, Science and Technology; the Ministry of Land, Infrastructure and Transport; and the Ministry of the Environment), a national program "Biomass Japan Strategy" was proposed and was approved by the cabinet in December 2002. One of the most important objectives of the strategy is CO_2 mitigation by promotion of the utilization of biomass as a substitute for fossil fuels. Many conversion technologies from biomass to energy have been proposed, and one of the most feasible technologies would be biomass-fired power generation.

In the present work, CO_2 mitigation was estimated based on life-cycle CO_2 analysis when woody biomass was burnt for power generation instead of coal. In this case, about 150 biomass-fired power plants having a capacity of 5 MW each could be operated in Japan. The analysis is based on the method previously reported [1].

2. PROCUREMENT OF WOODY BIOMASS

It is difficult to harvest, collect, and transport woody biomass from forestry land to plants at reasonable cost due to various inconveniences, such as steep mountains, inadequately developed infrastructure (e.g., work roads and machinery), and the excessive number of workers required. The report by Mitsubishi Research Institute, Inc. indicated that if 50% of the woody biomass that is potentially available in each prefecture in Japan can be collected, it is equivalent to 5% of the coal needed in a coal-fired power plant having a capacity of 1000 MW at least in 15 prefectures [1]. In practice, because the amount of biomass needed at one site is about 1000 tons (on dry basis) a day, such amount of woody biomass could be hardly collected for the reasons just mentioned . However, about 100 tons a day at one site could be possibly collected. Taking the procurement system into account, the construction of 150 biomass-fired power plants having a capacity of 5 MW each could be considered feasible in Japan. Next, the input energy required for harvest, collection, and transport, was estimated together with construction of the biomass-fired power plant, the output energy generated by biomass combustion, and the quantity of CO_2 mitigated.

3. HARVEST, COLLECTION AND TRANSPORT OF WOODY BIOMASS

For the calculation of life-cycle CO_2 analysis, the necessary energy and CO_2 emission must be estimated when woody biomass is harvested, collected and transported, therefore the following conditions were assumed. About 100 tons/day of woody biomass is collected from one site for a 5 MW power generation plant. The low heating value of woody biomass is assumed to be 4800 kcal/kg. The previous report made by Fuji Research Institute Corporation which was sponsored by NEDO indicated that for a 10 MW biomass-fired electricity generation, 1064 tons of CO_2 a year is emitted through harvest, collection, and transport of woody biomass [3], therefore 532 tons of CO_2 would be emitted for 5 MW electricity generation. In the present work, this value was adopted for the estimation.

4. POWER GENERATION

The annual electricity generated was estimated for a 5 MW plant which was about 100 tons of woody biomass a day. Table 1 shows the specifications of this system. If about 36 500 tons of woody biomass a year is supplied, the annual heat value generated by woody biomass combustion is calculated as follows:

$$\text{Annual heat value by woody biomass combustion} = 36\,500\ [t/y] \times 1000\ [kg/t] \times 4800\ [kcal/kg] / 1000\ [kcal/Mcal] = 1.75 \times 10^8\ Mcal/y$$

$$\text{Annual electric supply} = 1.75 \times 10^8\ [Mcal/y] \times 0.15 / 0.86\ [Mcal/kWh]$$

The report by Mitsubishi Research Institute, Inc. indicated that for the existing biomass-fired power plant having a capacity of 5 MW, the efficiency of power generation is about 15% [2]. In the present work, this value was adopted; hence, the annual electric supply is calculated as follows:

$$\text{Annual electric supply} = 1.75 \times 10^8\ [Mcal/y] \times 0.15 / 0.86\ [Mcal/kWh] = 3.06 \times 10^7\ kWh/y$$

Table 1 Specifications of the System

Annual amount of woody biomass [t/y]	36 500
Heating value of woody biomass [kcal/kg]	4800
Efficiency of power generation [%]	15
Annual electricity supply [kWh/y]	3.06×10^7
Capacity factor [%]	70
Plant capacity [kW]	4983
Energy for chipping [kWh/y]	3.04×10^3
Annual net electricity supply [kWh/y]	3.06×10^7

If the capacity factor is assumed to be 70%, the rated plant capacity of the biomass-fired power plant is calculated as follows. This is equivalent to a power plant having a capacity of about 5 MW.

$$\text{Rated plant capacity} = 3.06 \times 10^7 \text{ [kWh/y]} / 0.70 / 8{,}760 \text{ [h/y]} = 4983 \text{ kW}$$

It is necessary to chip woody biomass as pre-treatment in order to use it for power generation. The report by the Plastic Waste Management Institute indicated that in the pulp industry in Japan, the electric consumption for chipping wood is 0.0832 kWh/t [4], therefore the energy for chipping is calculated as follows:

$$\text{Energy for chipping} = 0.0832 \text{ [kWh/t]} \times 36{,}500 \text{ [t/y]} = 3.04 \times 10^3 \text{ kWh/y}$$

This value is relatively small by 4 orders of generated energy; therefore, this energy is substantially negligible. Accordingly, the annual net electricity generated is estimated to be 3.06×10^7 kWh/y.

5. CO_2 MITIGATION EFFECT BY BIOMASS-FIRED POWER GENERATION

Uchiyama and Yamamoto evaluated the amount of materials and energy needed for the construction of the coal-fired power plant having a capacity of 1000 MW, and then estimated CO_2 emission by utilizing the materials, electricity and other energy sources (Tables 2 and 3) [5]. According to the calculation method in the coal-fired power plant, the CO_2 emission was calculated for the materials, other energy sources and electricity which were utilized for the construction of the biomass-fired power plant. Construction materials such as steel, aluminum, and concrete, and energy sources such as coal, oil, and electricity were taken into account. Table 4 shows the CO_2 emission factors of these materials, energy sources and electricity [6]. As mentioned before, the plant capacity was about 5 MW. Since the capacity of the coal-fired power plant (1000 MW) is quite different from that of the biomass-fired power plant, the 0.7th power rule is expediently applied for the small capacity biomass-fired power plant. The composition of materials and energy needed for the construction of the biomass-fired power plant was assumed to be similar to that of a coal-fired power plant. The amount of materials and energy needed for the construction of the biomass-fired power plant are shown in Table 2. The CO_2 emission from the construction of the biomass-fired power plant is shown in Table 3. The annual CO_2 emission is also shown in Table 3 if the lifetime of the biomass-fired power plant is 30 years. Accordingly, the annual CO_2 emission for the construction of the biomass-fired power plant was estimated to be 110 tons.

Table 5 shows the overall results. As mentioned before, 532 tons of CO_2 a year is emitted through harvest, collection, and transport, and 110 tons of CO_2 a year is emitted for the construction. Tahara, et al. reported that CO_2 emission was 1.02097 kg-CO_2/kWh for coal-fired power generation, taking CO_2 emitted through marine transportation, coal combustion, and construction of the power plant into account [1]. In the present work, all materials needed for construction were assumed to be domestically provided. The amount of mitigated CO_2 was evaluated when woody biomass was burnt for power generation instead of coal as follows:

$$\text{The amount of } CO_2 \text{ mitigated by burning woody biomass instead of coal} = 1.02097 \text{ [kg-}CO_2\text{/kWh]} \times 3.06 \times 10^7 \text{ [kWh/y]} / 1000 \text{ [kg/t]} = 3.12 \times 10^4 \text{ t-}CO_2\text{/y}$$

Accordingly net CO_2 mitigation at one site for a 5 MW power plant is estimated as follows:

$$\text{Net } CO_2 \text{ mitigation at one site} = 3.12 \times 10^4 \, [t\text{-}CO_2/y] - 5.32 \times 10^2 \, [t\text{-}CO_2/y] - 1.10 \times 10^2 \, [t\text{-}CO_2/y] = 3.06 \times 10^4 \, t\text{-}CO_2/y$$

Table 2 Amount of Materials and Energy Required for Construction of Power Plants

	Coal-fired power plant [4]	Biomass-fired power plant
Capacity [MW] 0.7th order factor	1000	4.98 (x 0.024)
Steel [t]	62 200	1520
Aluminum [t]	624	15
Concrete [t]	178 320	4358
Coal [t]	14 339	350
Oil [t]	709	17
Electricity [MWh]	12 700	310

Table 3 CO_2 Emission from Construction of Power Plants

	Coal-fired power plant [4]	Biomass-fired power plant
Capacity [MW] 0.7th power factor	1000	4.98(x 0.024)
Steel [t-CO_2]	73 367	1794
Aluminum [t-CO_2]	1270	31
Concrete [t-CO_2]	17 722	436
Coal [t-CO_2]	34 175	834
Oil [t-CO_2]	2279	56
Electricity [t-CO_2]	5561	137
Total [t-CO_2]	134 374	3287
Annual CO_2 emission [t-CO_2/y]	4479	110

Table 4 CO_2 Emission Factors for the Construction Materials, Energy Sources and Electricity

Materials and energy	CO_2 emission factor
Steel [kg-CO_2/kg]	1.18
Aluminum [kg-CO_2/kg]	2.04
Concrete [kg-CO_2/kg]	0.10
Coal [kg-CO_2/kg]	2.38
Oil [kg-CO_2/kg]	3.22
Electricity [kg-CO_2/kg]	0.44

Table 5 Overall Results of a 5 MW Biomass-Fired Power Plant

CO_2 emission from construction of a biomass-fired power plant [t-CO_2/y]	110
CO_2 emission from harvest, collection, and transport [t-CO_2/y]	532
CO_2 mitigated by burning woody biomass instead of coal [t-CO_2/y]	31 200
Net CO_2 mitigation at one site [t-CO_2/y]	30 558
Total CO_2 mitigation by 150 biomass-fired power plants [t-CO_2/y]	4.58 million

As mentioned before, taking the procurement system into account, the construction of 150 biomass-fired power plants having a capacity of 5 MW each can be considered feasible in Japan, therefore the total CO_2 mitigation effect by biomass-fired power generation is estimated to be 4.58×10^6 t-CO_2/y.

In accordance with the Kyoto Protocol, Japan is required to reduce greenhouse gas emissions by 6% (as compared with the level in 1990) during the first commitment period from 2008 through 2012. The Energy Conversion Center reported that 1052 million tons of CO_2 was emitted in 1990 [7]; thus, about 63 million tons of CO_2 has to be reduced. The CO_2 mitigation estimated in the present work is equivalent to 7.3% of the required CO_2 mitigation. Accordingly, the biomass-fired power plants construction proposed in the present work is considered to have a potential to meet the Kyoto Protocol target for Japan.

6. CONCLUSIONS

CO_2 mitigation was estimated based on life-cycle CO_2 analysis when woody biomass was burnt for electricity generation instead of coal. In this case, about 150 biomass-fired power plants having a capacity of 5 MW each could be operated in Japan. About 30 600 tons of CO_2 a year can be mitigated by a 5 MW biomass-fired power plant, therefore the total CO_2 mitigation by 150 biomass-fired power plants was estimated to be about 4.58 million tons of CO_2 a year. The CO_2 mitigation estimated in the present work is equivalent to 7.3% of the CO_2 mitigation required in the Kyoto Protocol target. Accordingly, the biomass-fired power plants proposed are considered one of the potential countermeasures to prevent global warming.

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8. REFERENCES

[1] Tahara, K.; Kojima, T.; Inaba, A.; Ogi, T.; and Yokoyama, S. 1998. Reduction in CO_2 emission by biomass power generation with sustainable afforestation – evaluation by LCA. *Journal of the Japan Institute of Energy* 77(5): 403-409.

[2] Mitsubishi Research Institute, Inc. Report. December 2002.

[3] NEDO-GET-9603. 1997. NEDO Report.

[4] Plastic Waste Management Institute. 1993. Plastic Waste Management Institute Report.

[5] Uchiyama, Y. and Yamamoto, H. 1992. Greenhouse Effect Analysis of Power Generation Plants. CRIEPI Report, Y91005.

[6] Tahara, K.; Kojima, T.; and Inaba, A. 1997. Estimation of power plants by LCA. *Journal of Chemical Engineering of Japan* 23(1): 88-94.

[7] Energy Conservation Center. 2004. Actual and Projected Final Energy Consumption and Energy-Related CO_2 Emissions, http://www.eccj.or.jp/result/eng/1.html.