$LCCO_2$ of coal co-firing with imported torrefied woody biomass in Japan

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Abstract. In response to Japan's increase on coal dependence, co-firing of woody biomass in a coal power plant has been considered as the most feasible sustainable alternative. We propose torrefaction as an effective method to improve the quality of biomass fuel. To measure how much CO_2 can be avoided by utilizing torrefied fuel, Life Cycle CO_2 ($LCCO_2$) of woody biomass co-firing in the Japanese coal power plant was conducted in this study. As a comparative analysis in the $LCCO_2$, scenarios constructed included the use of woody biomass in the form of chip, pellet, and torrefied fuel. Due to the unavailability of large quantity domestic feedstocks in Japan, Indonesia was chosen as the origin of the imported woody biomass in the simulated scenarios. The results showed that significant CO_2 reduction could be achieved especially in the co-firing that includes torrefied fuel. In the case where 30cal% of torrefied fuel or 5cal% of pellets were used for co-firing in a 50 MW capacity coal power plant, 95,000 t of CO_2 could be avoided annually compared to using 100% coal.

1 Introduction

Traditional use of bio-energy, such as direct burning for heating and cooking in households, constitutes more than 50% of the world's consumption of biomass and waste resources in 2015 [1]. This fact imply that resources are available and accessible, but they have not been efficiently utilized into modern energy.

The aim of this study is to conduct a life cycle CO_2 ($LCCO_2$) simulation of the use of various types of woody biomass as advanced biofuels in a coal firing plant replacing a certain amount of coal to carry out biomass co-firing. By conducting a $LCCO_2$ simulation, we expect to identify which type of biomass fuel has the highest potential to reduce CO_2 emissions. There are three types of woody biomass fuel to be compared in this study: (a) chipped, (b) pelletized, and (c) torrefied. In addition to an $LCCO_2$ simulation, we have conducted an experiment to determine if it is possible to improve the energy efficiency of the torrefaction process by recovering waste heat and using it to dry the raw material. The assumed type of biomass used in this study was woody biomass from Indonesia, and the output was assumed to be co-fired in a coal power plant in Japan. This strategy is proposed

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in response to the Japanese increasing dependence on coal after the accident at the Tokyo Electric Power Daiichi Fukushima nuclear power plant [2].

Compared to other renewable energy options, biomass co-firing may be considered as the lowest risk, least expensive, and most efficient and can be conducted immediately as the resources become available [3]. Common biomass pre-treatment processes are chipping and pelletizing for size-reduction and compacting techniques. The weakness of woodchip and wood pellet fuels is that there is only a small percentage (less than 5%) that can be used in a coal power plant as a co-firing material [3]. However, IHI company has newly-developed a technology that allows wood pellet mixing ratio up to between 50% [4].

Torrefaction is the process of heating biomass in the absence or drastically-reduced presence of oxygen to a temperature of about 250°C to 320°C [5]. Before the heating process, drying is often recommended to achieve a certain level of moisture (typically about 10-15 %) to improve the efficiency. In the process, volatile matters (about 20%) are lost and the character of the original biomass becomes drastically changed. The changes include becoming more brittle, improved grindability, and becoming less absorbent of moisture [6]. In this particular study, heat recovered from the torrefaction process is used for drying. Our laboratory previous study has shown that the torrefaction results allowed 100% replacement of conventional coal [7]. In this study, we conducted a torrefaction experiment to estimate whether the heat recovered from the process would be sufficient for the biomass feedstock drying process and thus make it energy self-sufficient for the whole process.

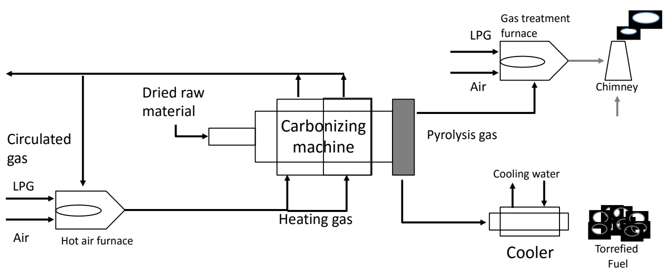

Fig. 1. Schematic diagram of experimental torrefaction equipment [8].

Japan has a significant amount of forest, especially in the Hokkaido prefecture area. However, the topography and landscape of the Japanese islands are not suitable for the collection and transportation of significant amounts of woody biomass from the forest (Fig. 2 and 3) [9].

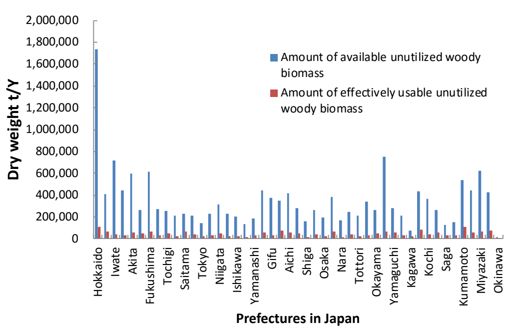

Fig. 2. Unutilized woody biomass availability [9].

Fig. 3. Distribution of unutilized woody biomass [9].

2 Methods

2.1 Heat recovery in torrefaction

To recover the low-grade waste heat from torrefaction process, we used Organic Rankine Cycle (ORC) system. It was chosen because it uses organic fluid that has a lower boiling point that enables the generation of electricity from lower temperature heat waste [10]. We tested whether the recovered energy is sufficient for the drying process in torrefaction.

2.2 LCCO$_2$

There scenarios constructed (CASES) are the following: CASE 0 is the baseline scenario that used 100% coal, CASE 1 used 3cal% (calorific percentage) of woodchips, CASE 2 used 5cal% wood pellets, CASE 3 used 30cal% wood pellets, and CASE 4 used 30cal% torrefied fuel (Fig. 5). This study only covers the CO_2 because changes in SOx and NOx levels when co-firing coal with biomass is already well researched [3, 11].

2.2.1 Goal and scope

The goal of this LCCO$_2$ is to identify the least CO_2 emitting fuel among the three constructed scenarios. With the considerations mentioned in the previous sections, the scenarios were constructed based on the following assumptions: (a) the source of the raw material is Indonesia, (b) land transport distance is 20 km, (c) raw material moisture content is 45%, (d) the torrefaction process takes place in Indonesia, (e) marine transportation is used from Indonesia to Japan, (f) co-firing is done in Japan, and (g) coal power plant generation efficiency in Japan is 38.9%. The system boundaries of the LCCO$_2$ conducted is shown in Figure 4.

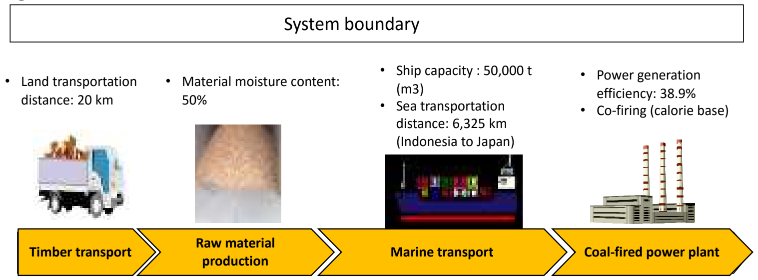

Fig. 4. LCCO$_2$ system boundary.

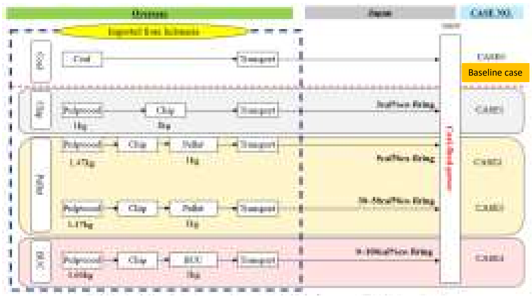

Fig. 5. LCCO$_2$ scenarios.

2.2.2 Inventory

As an $LCCO_2$ study, the inventory covers only the CO_2 emissions of each scenario constructed. The steps involved in the $LCCO_2$ boundary are the following: (a) land transportation for raw material, (b) fuel production, (c) marine transport, and (d) coal-fired power plant. The emission inventory for each step are presented in Tables 1 and 2. The other factors required to conduct $LCCO_2$ such as fuel density, calorific value, emission factor, and ship load capacity are presented in Tables 3 to 10.

Table 1. CO_2 emission from producing 1 kg of torrefied fuel.

Process Name	Unit	Value
Woodchip land transport	kg-CO_2	0.00471
Woodchip production	kg-CO_2	0.01151
Torrefied fuel production	kg-CO_2/kg	0
Total	**kg-CO_2/kg**	**0.01622**

Table 2. Property comparison between torrefied fuel and coal.

Item	Unit	Torrefied fuel	Coal
Density	kg/m^3	200	900
Calorific value	MJ/kg	22.3	26.6
CO2 emission	kg-CO_2/kg	0.1054	2.409

Table 3 CO_2 emission from each fuel type production.

Process Name	Unit	Woodchip fuel	Pelletized fuel	Torrefied Fuel
Wood material transportation	kg-CO_2/kg	0.0013	0.0019	0.0047
Woodchip production	kg-CO_2/kg	0.0031	0.0046	0.0115
Pellet Production	kg-CO_2/kg	-	0.4852	-
Torrefied fuel production	kg-CO_2/kg	-	-	0
Total	kg-CO_2/kg	0.0044	0.4917	0.0162

Table 4 Calorific value and CO_2 emission from the production and use of each type of fuel.

Item		Unit	Coal	Woodchip	Wood pellets	Torrefied fuel
Calorific value		MJ/kg	22.6	9.4	15.9	22.3
CO_2 emission	Production	kg-CO_2/kg	-	0.0044	0.4917	0.0162
	Use	kg-CO_2/kg	2.409	Carbon Neutral	Carbon Neutral	Carbon Neutral

Table 5 Density for each type of fuel.

Fuel type	Unit	Value
Coal	t/m^3	1.2
Woodchip	t/m^3	0.287
Wood pellets	t/m^3	0.697
Torrefied fuel	t/m^3	0.2

Table 6. Combustion rate.

Fuel type	Unit	Value
Woodchip	%	0.03
Wood pellets	%	0.05
		0.3 (IHI)
Torrefied fuel	%	0.3

Table 7. Ship capacity.

Fuel type	Unit	Value
Volume	m^3	45,000
Load weight	t	45,000

Table 8. Ship load weight capacity per 45,000m^3.

Fuel type	Unit	Value
Coal	t	54,000
Woodchip	t	12,915
Wood pellets	t	31,365

Table 9. Fuel volume per 45,000 t.

Fuel type	Unit	Value

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Coal	m^3	37,500
Woodchip	m^3	156,794
Wood pellets	m^3	64,562
Torrefied fuel	m^3	225,000

Torrefied fuel	t	9,000

Table 10. Indonesia–Japan transport emission.

Fuel type	**Unit**	**Value**
Distance	km	6325
Emission	kg-CO_2/t km	0.0141

3 Results and discussions

3.1 Heat recovery in torrefaction

The results from using the ORC system for heat recovery for the torrefaction pyrolysis gas showed that the energy generated was sufficient to run the torrefaction process. As comparative ratios, the heat necessary for drying the raw material is only 17.8 units, the 21.8 units of heat generated was more than sufficient for the drying process (Fig. 6). The actual value of energy and material balance from our commercial plant scale experiment (2 lines of 500 t/day capacity) of 3 MWh/h is shown in Figure 7. The energy density of the output fuel is improved after the drying process by 1.67 times, and by 2.33 times after the torrefaction process. This implies that there will be less amount of fuel required to generate the same amount of energy.

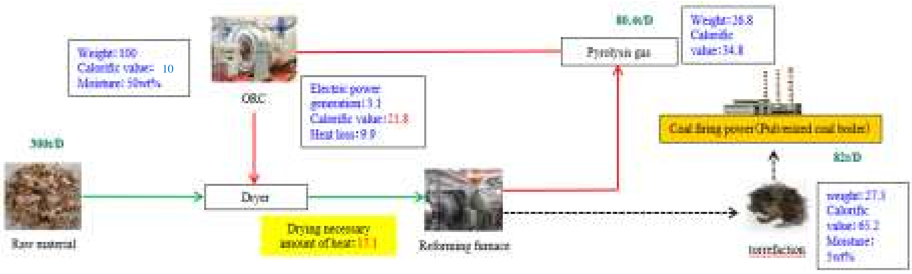

Fig.6. Material and energy balance in the energy-self-sufficient torrefaction process explained in ratio comparison.

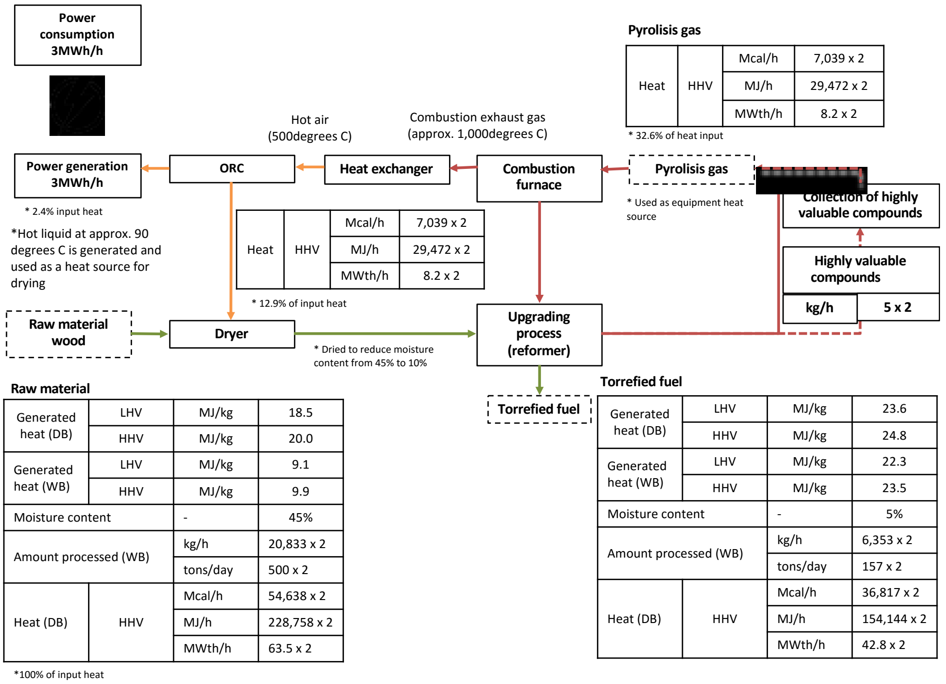

Fig. 7. Material and energy balance in the energy-self-sufficient torrefaction process with detailed properties (2 lines) [8].

3.2 $LCCO_2$

It is evident from the results (Fig. 8) that the two scenarios with the lowest CO2 emissions are CASES 3 and 4, with 17.8 t CO_2/y and 28.5 t CO_2/y emission reduction potentials respectively. However, in CASE 3, where the mix is 30cal% wood pellets, there is a significant amount of CO2 emissions from biomass (about 8,392 t CO_2/y) and higher emissions from transportation. CASE 4 with 30cal% torrefied fuel is then clearly the scenario with the lowest environmental load in terms of CO_2 emissions. For comparison, an additional scenario (CASE X) where a mix with 50cal% wood pellets (assuming the technology development by IHI would reach that level in the future) was simulated. The result was almost similar with the 30cal% torrefied fuel scenario (CASE 4) with a 29.7 t CO_2/y reduction potential.

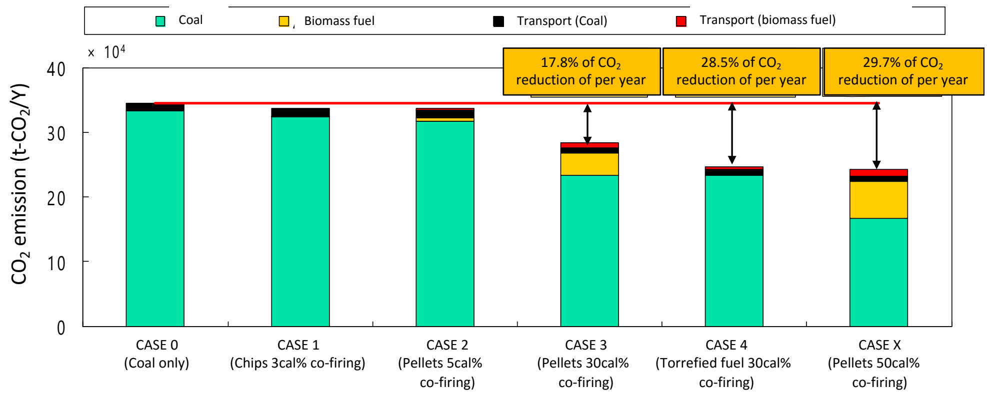

Fig. 8. CO_2 emission amount of each scenario.

Furthermore, because it is understood that mixing 50% of IHI special wood pellets and using 100% of our experimented torrefied fuel can be utilized for firing in a coal power plant, we ran a simulation to show what amount of raw material is required for various mixture percentage, how much CO_2 is emitted and from which part of activity within the scenario boundary are those CO_2 emitted. Figure 9 and 10 presents the simulation results. Depending of what the favorable and feasible situation is (for example, raw material availability, existence of Fit-In-Tariffs, transport and time considerations), one could identify what amount of biomass fuel mix ratio is optimal.

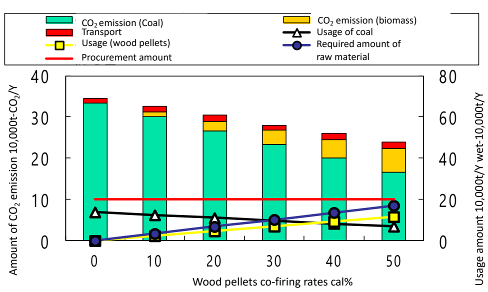

Fig. 9. CO_2 from co-firing wood pellets.

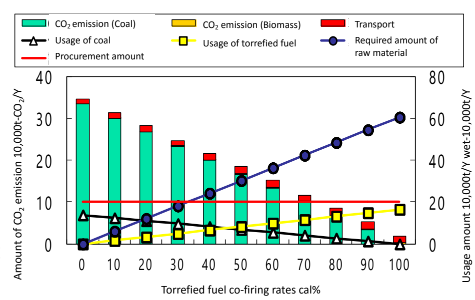

Fig. 10. CO_2 from co-firing torrefied fuel.

4 Conclusions

This study conducted an $LCCO_2$ evaluation to measure how much CO_2 emissions can be avoided by using varying amounts of biomass fuel in a coal power plant for co-firing. We found that the use of 30% torrefied fuel could reduce the amount of CO_2 emissions by about 28.5% or around 95,000 t annually.

Acknowledgements

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