LCA on Bio-H_2 fuel and/or Bio-electricity production system in Thailand and Malaysia

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Abstract In this paper, we focused on the Blue Tower (BT) gasification system which would be more suitable among the distributed energy systems. Through the system, we estimated the specific CO_2 emission and the energy intensity based on LCA methodology at the cases of Bio-H_2 fuel and/or Bio-electricity. Especially, using the biomass residues of cassava and bagasse in Thailand, and EFB in Malaysia, we executed the basic experiments on pyrolysis and reforming reaction, and designed BT plant. As a result, the energy conversion efficiency of Bio-H_2 was 30.07 to 43.70%, and that of Bio-electricity was 40.2 to 52.4%, respectively. Also, in the case of cassava, the specific CO_2 emission would be more disadvantageous due to the much CO_2 emission in the cultivation sub-process. From the viewpoint of energy payback ratio, that of Bio-H_2 is almost same as that of fossil fuel. On the other hand, compared with the CO_2 emission reductions of Bio-electricity generated from the bagasse and/or EFB, they do not have differences so much between the bagasse of 9.7 and the EFB of 9.9. Inversely, the energy payback ratio of EFB was worse than other cases (e.g. bagasse: 7.6, EFB: 11.1).

1 Introduction

The biomass is one of the renewable energy, and is expected as relief of global warming and an alternative energy source of fossil fuel by utilizing biomass energy. Among the countries of Southeast Asia, it is positive to the measure which used the biomass for promotion of reduction of a fossil fuel dependence, and agriculture. In Thailand, the policy through which the bio-ethanol using molasses discharged at the sugar factory and excess cassava chip is spread is implemented. The demand of ethanol would be 3 million liters per a day in 2011, for use in making octane 95 gasohol, although Thailand's existing ethanol plants are able to produce 825,000 liters/day at present [1]. Therefore, it counts upon bio-ethanol plants being extended from now on.

The Thailand government has set up the introductory target of alternative energy, such as bio-ethanol, a bio-diesel, photovoltaic generation, wind electricity, and hydrogen energy, with 20.3% (an equivalent for 19800ktoe) by 2020 [2]. Therefore, it is necessary to take the use form of various energies into consideration over the future.

In Malaysia, the "National Biofuel Policy" which promotes the production and the spread of bio-diesel fuel due to palm oil for the purpose of decrease of oil dependence has been carried out [3]. The biodiesel plants in Malaysia are setting up for exports. Also, it becomes important using effectively biomass waste discharged with production of Bio-fuel. At present, there is a continuously increasing interest in the utilization of oil palm biomass as a source of clean energy. One of the major interests is hydrogen from oil palm biomass. Hydrogen from biomass is a clean energy source, and is expected to take a significant role in the future energy demand due to the renewable raw material availability [4]. Also, it is expected that the economic growth in Asia becomes more active in the future. Therefore, if the energy alternatives are taken into consideration, the biomass utilization would be expanded in the various applications. As we mentioned previously, hydrogen is clean energy because of only generating water when it burns. The added value of cleaner energy can be obtained by hydrogen production from biomass feedstock which is zero emissions due to the carbon neutral additionally. The demand of hydrogen is increasing even in Southeast Asia, for instance, Air Products announced that it is building a new hydrogen production facility which will have a hydrogen production capacity of more than 1.5 million standard cubic feet per day in West Port, Selangor, Malaysia to support increasing product demand in the region [5].

In this research, on the promotion possibilities of the biomass gasification system, whose feedstock are the biomass residues such as cassava chips and bagasse in Thailand, and EFB (Empty Fruit Bunches) in Malaysia, were analyzed. In particular, we focused on the Bio-electricity and Bio-H_2 production systems and estimated the specific CO_2 emissions based on Life Cycle Assessment (LCA).

So far, in the biomass LCA analyses, the pre-processing processes of chipping, transportation and drying of feedstock, and the energy conversion process of production energy of electricity and/or H_2 fuel were considered. Here, in the energy conversion process, we considered the auxiliary power of each plant based on the simulation data obtained by the results of pyrolysis and reforming experiments. These results would be extremely significant from the viewpoint of the usage increase of waste biomass resources in Asia.

2 Methodology

2.1 System boundary and CO_2 basic units

The system boundary is shown in Fig. 1. We define the system boundary in the biomass energy system. In this study, we focused on the unused and/or waste biomass feedstock. The system boundary is including from the generation stage of biomass to that of production of Bio-fuel. That is, in the case of cassava in Thailand, we aimed at the availability of excess cassava, and the system boundary has the processes of cultivation, chipping, transportation to BT plant and the energy conversion through BT. Also, the specific CO_2 emission for each factor in this study is shown in Tab.1.

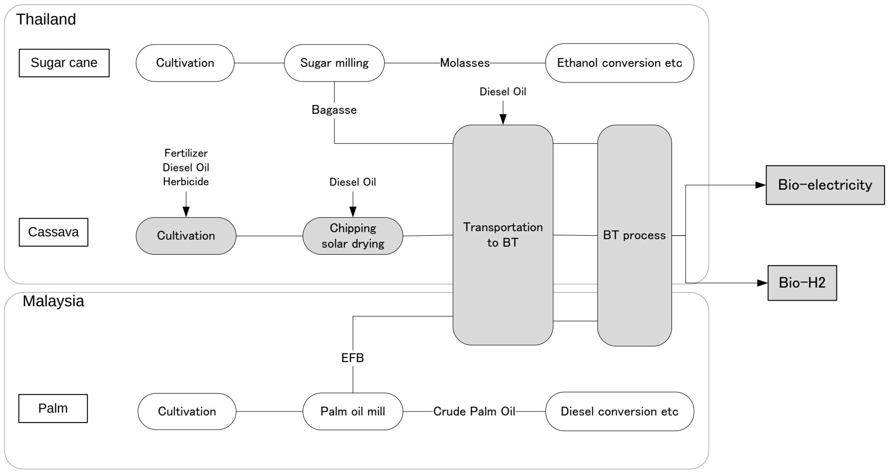


Fig.1: System boundary

Tab.1: Specific CO_2 emission for each factor

		Unit	Thailand	Malaysia
Fertilizer	N	kg-CO_2/kg	28.0	34.8
	P_2O_5	kg-CO_2/kg	4.4	5.4
	K_2O	kg-CO_2/kg	9.1	11.3
Electricity		g-CO_2/MJ	147.0	182.2
Coal		g-CO_2/MJ	111.6	111.6
Diesel Oil		g-CO_2/MJ	76.1	76.1

2.2 Cultivation process

In Northern Thailand which has 17 provinces, cassava is cultivated as energy crops for Bio-electricity and/or Bio-H_2 production. The locations of cassava fields are specified by the land use map developed by Ministry of Agriculture and Cooperatives and Ministry of Industry [6, 7]. In particular, we focused on 11 provinces in the case of sugarcane and 13 provinces of cassava.

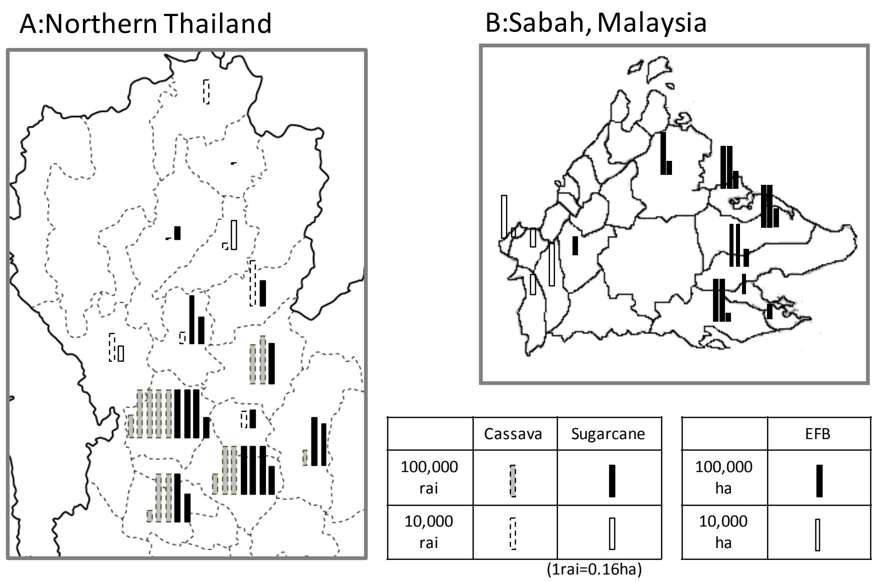


Fig. 2 Planted area of cassava, sugarcane in Northern Thailand (A) and palm in Sabah, Malaysia (B)

Tab.2: Fertilizers (N, P_2O_5 and K_2O), herbicides and diesel for farm machineries for cultivation of cassava

Fertilizer			Herbicide	Diesel oil for cultivation
N	P_2O_5	K_2O		
kg/ha	kg/ha	kg/ha	kg/ha	L/ha
49	46	58	3.85	46

On the other hand, in Sabah Malaysia, which is becoming an important state for both palm production and life's diversity, we focused on 12 provinces [8]. The annual harvest yield of sugarcane and cassava were 3.87×10^4- 4.62×10^6 t/yr and

7.35×10^2-1.50×10^6 t/yr, respectively. That of FFB (Fresh Fruit Bunch) was 22.47×10^6 t/yr. Here, the target area and the cultivated acreage of sugarcane, cassava and FFB are shown in Fig. 2. The detailed numerical data of cassava on fertilizer (N, P_2O_5 and K_2O), herbicides and diesel used for farm works were estimated from the results of Nguyen et al. [9] (see Tab. 2).

2.3 Transportation

Each truck capacity for cassava chip, bagasse and EFB was assumed to be 10 tons or 4 tons. The specific CO_2 emissions in the transportation sector are indicated as a function of the load ratio against total weight. For instance, the load ratios in the 10t-truck which is in the transportation for excess cassava chips and bagasse are assumed to be 70%. Note that the transportation distance is from the methanol production facilities to BT plants.

Using the load ratio of λ, the fuel consumption rate of 10 ton-truck or 4 ton-truck is shown as Eq. (1)

$$f_{FC}(\lambda) = a\lambda + 2b \tag{1}$$

Where, the coefficients of a and b on CO_2 intensities are shown at Tab. 3. Also, transportation distance is based on the road map.

Tab.3: Truck capacity, CO_2 emission factor and loading ratio for transportation of biomass residues

	Unit	Thailand	Malaysia
Truck capacity	Ton	10	4
Factor a	g-CO_2/km	670	268
Factor b	g-CO_2/km	476	275
Load ratio λ	%	Outward: 70%, Return: 0%	

2.4 BT process

2.4.1 Basic experiments on pyrolysis and steam reforming

Next, we executed the basic experiments on the BT process reactions such as pyrolysis and steam reforming reactions in order to estimate CO_2 emission. In this study, the CO_2 emissions on the production of Bio-electricity and/or Bio-H_2 were evaluated by the process design (see Figs.3 and 4).

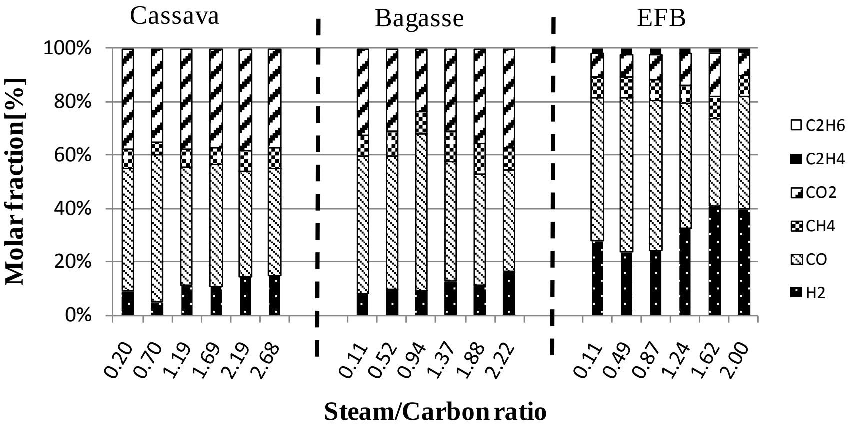


Fig.3: Results of pyrolysis experiments

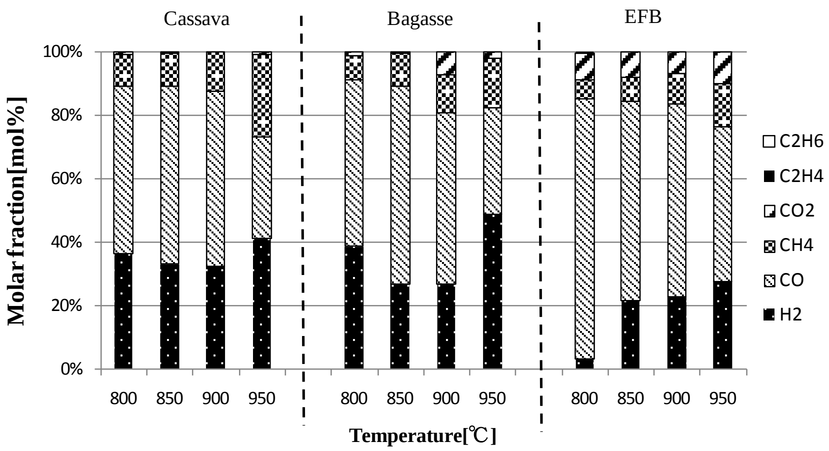


Fig.4: Results of steam reforming experiments

In the pyrolysis experiment, approximately 0.2 g of sample was set in the furnace, and the water required for reactions was injected into the furnace between 0 and 250μL. In this experiment, the reaction temperature raised up to 550 deg. C. According to the pyrolysis results, the mole fraction of hydrogen would be concentrated by increasing water. In any biomass materials, it was implied that the molar fraction of hydrogen would be saturated at 250μL. On the other hand, according to the specification of BT plant operation condition, the water is based on the ratio of steam vs. carbon in the feedstock (S/C), that is, SC=1.0 is arranged. This condition would be suitable for the reforming condition, too. Due to this reason, in the reforming experiment, the water feeding conditions were 150μL for cassava and bagasse, and 200μL for EFB, respectively. Likewise, the experimental temperature was from 800 to 950 deg. C (see Fig.4). Due to the results, the appropriate condition was obtained so that the hydrogen molar fraction is a maximum. In this study, we understood that the temperature was 950 deg. C which is the same as the operation condition of BT plant in practice use.

Next, the ultimate analysis data of each feedstock and char is shown in Tabs. 4 and 5, respectively.

Tab.4: Ultimate analysis of cassava, bagasse and EFB

	Unit	Cassava	Bagasse	EFB
C	wt%	37.33	42.19	47.6
H	wt%	5.79	5.63	5.75
O	wt%	56.01	51.64	40.26
N	wt%	0.87	0.54	0.95
Ash	wt%	10.28	2.98	4.7
Volatilization rate	wt%	79.93	85.41	75.9
Moisture content	wt%	10.21	6.62	7.56
Higher heating value	MJ/kg	14.73	15.67	19.67

Tab.5: Ultimate analysis of char

	Unit	Cassava	Bagasse	EFB
C	wt%	52.52	80.03	73.4
H	wt%	1.67	2.25	1.67
O	wt%	45.33	17.33	24.58
N	wt%	0.48	0.39	0.71
Higher heating value	MJ/kg	21.99	31.01	26.48

Based on the experimental results and the ultimate analysis data, the synthesis gaseous components after reforming reaction were as follows. Note that the material balances for 1kg feedstock were as the following Eq. (2)-(4) [10].

[Cassava]

$$C_{37.33}H_{5.79}O_{45.72}N_{0.87}+47.06H_2O \rightarrow 16.60H_2+0.66CO_2+48.92H_2O+3.26CH_4$$

$$+19.69CO+0.26N_2+\text{Other (Char etc)} \qquad (2)$$

[Bagasse]

$$C_{42.19}H_{5.63}O_{48.65}N_{0.54}+46.83H_2O \rightarrow 20.23H_2+1.70CO_2+48.82H_2O+1.79CH_4$$
$$+22.85CO+0.17N_2+\text{Other (Char etc)} \qquad (3)$$

[EFB]

$$C_{47.80}H_{5.75}O_{40.26}N_{0.95}+61.23H_2O \rightarrow 18.48H_2+2.25CO_2+59.19H_2O+3.77CH_4$$
$$+18.54CO+0.27N_2+\text{Other (Char etc)} \qquad (4)$$

2.4.2 Bio-electricity and Bio-H_2 production

The BT process design was performed based on the steam gasification experiment. As a result, in the case of Bio-electricity, assuming that the scale of BT plant was shifted to 12, 24 and 48 t/d, the net power output was shown in Fig. 5.

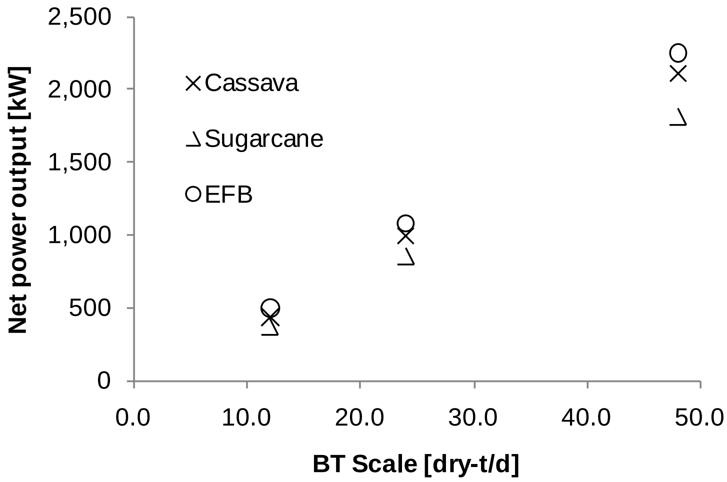


Fig.5: Net power output for BT scale (Bio-electricity case)

In the case of Bio-electricity, extending the plant scale, the net power output (electricity) will be increased. Simultaneously, the energy efficiency would be improved. According to our estimation, the energy efficiencies were 40.2 to 47.5 % of cassava, 40.2 to 48.4 % of sugarcane, and 45.4 to 52.4 % of EFB, respectively.

Likewise, we simulated the performance of BT plant whose scale was assumed to be 30 t/d. Note that the plant scale was same for each feedstock. Here, the performance of Bio-H_2 production system is shown in Tab. 6. The H_2 refinery efficiencies were 30.07% of cassava, 43.70% of bagasse, and 39.53% of EFB, respectively.

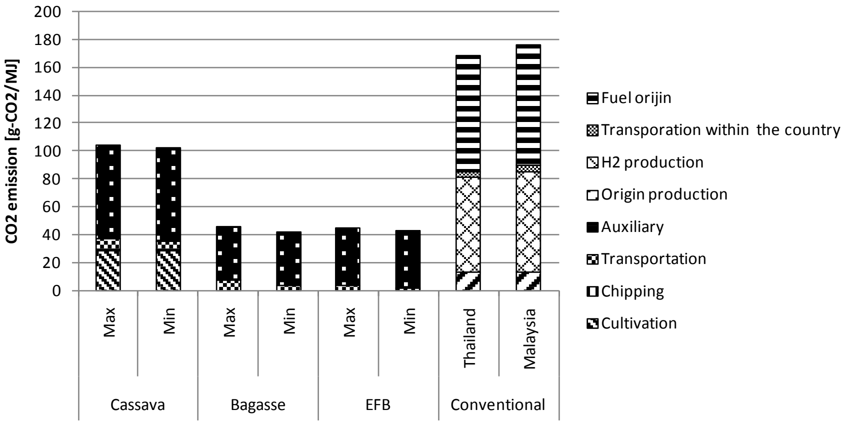
Tab.6: Performance data of Bio-H_2 plant 30t/d

	Unit	Cassava	Bagasse	EFB
Feed Biomass	kg/h	1,250	1,250	1,250
	MJ/h	14,733	16,678	17,804
Net Product Gas	Nm3/h	1,203	1,245	1,124
	MJ/h	16,290	14,958	14,847
Energy Eff.	%	86.22	71.24	60.00
Auxiliary Power	kW	560	532	447
Bio-H_2	MJ/h	4,431	7,288	7,037
Refining Eff.	%	30.07	43.70	39.53

3 CO_2 emission and energy payback ratio

Next, based on CO_2 analyses of the described system, life cycle CO_2 ($LCCO_2$) of Bio-electricity and Bio-H_2 were estimated. Fig.6 shows the results of $LCCO_2$ emissions for Bio-electricity and Bio-H_2 per MJ in comparison to the conventional cases in Thailand and Malaysia. On the specific data, we used ones in the target countries, however, if the data was not existing, the Japanese ones were referred [11].

(A) Bio-H_2



(B) Bio-electricity

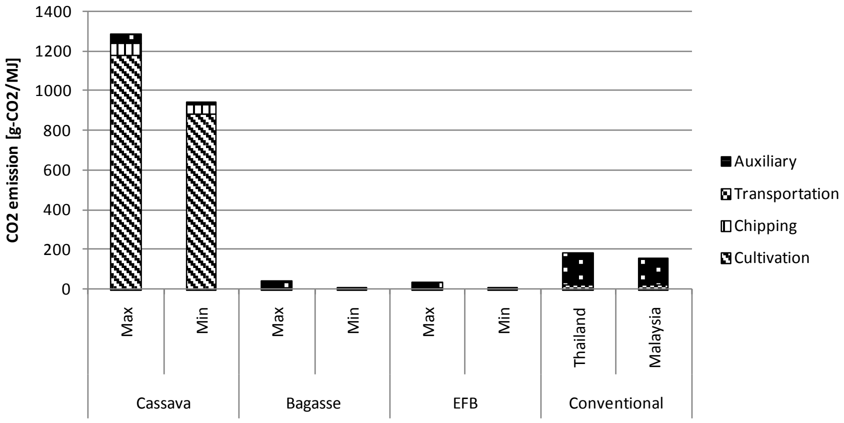


Fig.6: Results of $LCCO_2$ analysis (A: Bio-H_2, B: Bio-electricity)

One of the major results of Bio-H_2 is their lower CO_2 emissions in comparison to the conventional ones in both Thailand and Malaysia.

Especially, on the items of the CO_2 emission discharged in the case of Bio-H_2 from cassava, the emission in the cultivation process would occupy 27% of the whole system. Also, the emission of H_2 production would occupy 49%, after 41% of materials origin.

Second, as described in Fig.6 (B: Bio-electricity), the CO_2 emission of Bio-electricity from cassava was around 5 to 8 times against that of conventional electricity. The specific CO_2 emission of the whole system would be affected by large CO_2 emission in cultivation process which corresponds to 92 to 94%.

Next, we assumed the energy payback which is the ratio of total energy produced during a system's normal lifespan. Here, the energy payback ratio is shown as Eq. (5). Also, CO_2 reduction ratio is defined as Eq. (6). In analyses of energy payback and CO_2 reduction ratios, we used the data in 30 t/d of Bio-H_2 production case, and 12, 24 and 48 t/d of Bio-electricity one.

$$Energy\_payback\_ratio = \frac{Energy\_output}{\sum Energy\_input} \tag{5}$$

$$CO2\_reduction\_ratio = \frac{CO2\_emission\_of\_biofuel\_production}{CO2\_emission\_of\_conventional} \tag{6}$$

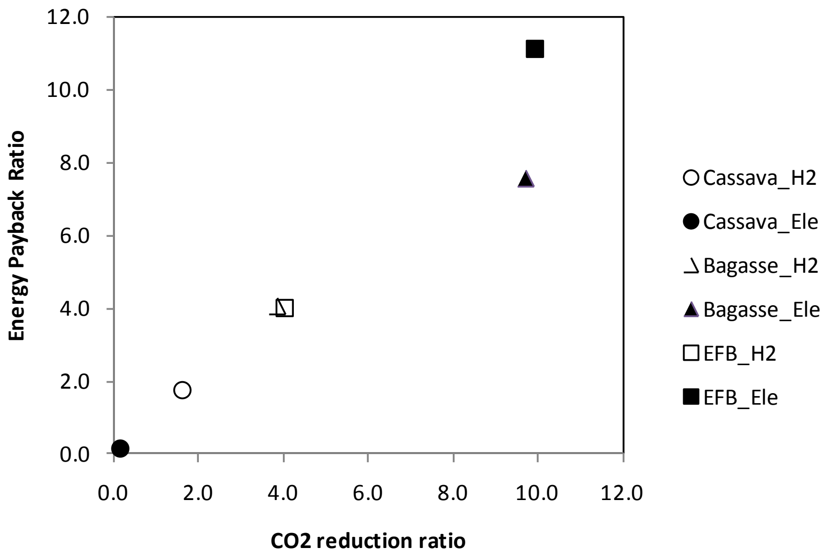


Fig.7: Results of energy payback and CO_2 reduction ratios

From the above results, the rate of Bio-H_2 is almost same as that of fossil fuel. In this study, the energy payback ratios were between 1.6 and 7. In the case that the electricity due to bagasse is compared to the electricity of EFB, the CO_2 reduction ratios do not have differences so much between the bagasse of 9.7 and the EFB of 9.9. Inversely, the energy payback ratio of EFB was worse than other cases (e.g. bagasse: 7.6, EFB: 11.1).

Since the Bio-electricity produced by cassava consumed much energy in cultivation process, both energy payback and CO_2 reduction ratios would be worse. Compared to those of the Bio-H_2 and Bio-electricity in the same feedstock, it was indicated that the Bio-H_2 production using cassava was advantage, and that the Bio-electricity using bagasse or EFB was much better. Although we argued the 30 t/d scale only for Bio-H_2 in this study, by enlarging BT scale, it is expected that the energy payback and CO_2 reduction ratios become large, that is, it would shift to the upper-right position in Fig. 7.

4 Conclusions

Due to a comprehensive energy and CO_2 aspect analysis, we provided a fair comparison between the two bio-energy alternatives. The relationship between energy efficiency and CO_2 reduction were shown by the indexes of energy payback and CO_2 reduction ratios. In particular, we found out that the cultivation process of cassava consumed much energy. The indexes were affected by the energy intensity. In the introduction of energy production system using biomass waste feedstock, it would be extremely significant to take some factors into consideration simultaneously. Although the energy payback and CO_2 reduction ratios were used in this study, we would like to execute the analysis including the energy demand, the production cost and the marketability.

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