Chapter 3

Case Studies

December 2019

This chapter should be cited as
ERIA (2019), 'Case Studies', in Yasuo, O., Y. Fumiko and H. Phoumin (eds.), *Study on the Biomass and Coal Co-combustion in the ASEAN Region.* ERIA Research Project Report FY2018 no.17, Jakarta: ERIA, pp.39-53.

Chapter 3
Case Studies

1. Prerequisites of Case Studies

1.1. Generation capacity

In the ASEAN region, large-scale coal-fired power plants based on energy plans are in operation or in construction, and the electrification rate in urban area has reached more than 90%. Therefore, construction of power plants in rural areas is expected to increase in the future due to improved rural electrification rate. However, the present power plants are small and medium scale because the local power grid is not developed yet and the transmission capacity is small. Additionally, if agricultural waste would be used as biomass fuel to generate electricity, the amount of waste that could be procured and supplied from areas surrounding the power plant is important.

From such situation, the generation capacity in each case study is set to 50 MW.

1.2. Boiler

(1) Fuel tolerance range

The CFB boiler used in this study is configured so that air intake from the bottom of the furnace causes the even mixture of fuels and high-temperature combustible materials inside the furnace. Following combustion, the mixture is returned to the furnace bed and blown upward. The fuel is repeatedly subjected to this process inside the furnace, making it a boiler technology that offers extremely high fuel efficiency. On the other hand, the system is highly adaptable to a wide range of fuels – from waste products to low-rank coal. Its superior fuel adaptability is a vital property for use in developing countries where there is a strong desire to use biomass fuels as a way of reducing CO_2 emissions and promoting the domestic use of low-rank fuel sources.

CFB boilers can tolerate an extremely wide range of fuels. It is possible to develop a relatively large-scale boiler to use fuels that could not be used with conventional pulverised coal combustion boiler or stoker boiler. One great attribute of the CFB boiler is that low-value or low-quality fuels can be used to produce electricity economically.

(2) Reducing operating and maintenance burden

CFB boilers have a low internal combustion temperature and they do not experience localised overheating due to fluidised combustion. As a result, they are unique in that they produce extremely low levels of ash, slag, or scale deposits on the furnace wall; the risk of high-temperature clinker generation at the bottom of the furnace is also extremely low.

As a result, long-term sustained operation, particularly during low melting point combustion, is possible and the frequency of facility maintenance inspections can be constrained. Furthermore, fly ash produced during combustion is almost completely burnt so it is often converted to be used as cement materials. Also, foreign objects mixed in the fuel are discharged via a grid; so, bottom ash can be used as a resource.

(3) Reducing environment load

As indicated in (1), CFB boilers enable the highly efficient use of biomass fuels and waste material fuels in power generation facilities and, thus, are effective as a CO_2 reduction measure (global environmental load). Also, the system enables low-NOx operation because the fuel properties and structural characteristics of the circulating fluidised bed system result in the production of very low amounts of NOx.

Inserting pulverised limestone together with the fuel into the furnace results in desulphurisation above 90%. This is a simple method that would be particularly attractive for regions lacking in technological advancement. The low global environmental load (particularly NOx and SOx) and environmental robustness are also highly environment friendly.

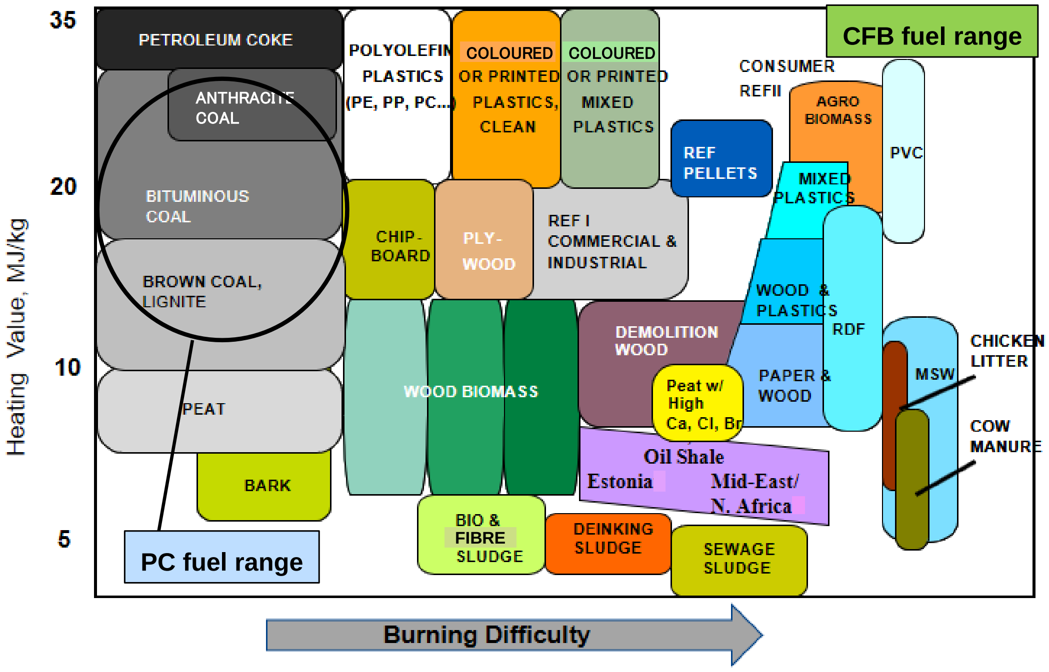
As indicated by cases in Japan, this system can resolve the problem of waste materials (garbage problem) that occurs with economic growth in developing countries. As such, this system can make social contributions to the environment.

When facing more difficult demands for environmental performance, urea can be inserted into the cyclone to conduct non-catalytic denitrification. Even when faced with the stricter urban environmental measures of an advanced nation, these requirements can be met by installing an external desulphurization unit and an external denitrification unit, systems required as permanent installations on systems of pulverised coal combustion boilers and stoker boilers.

This technology enables social contributions in the area of global emissions, local emissions, and life environment.

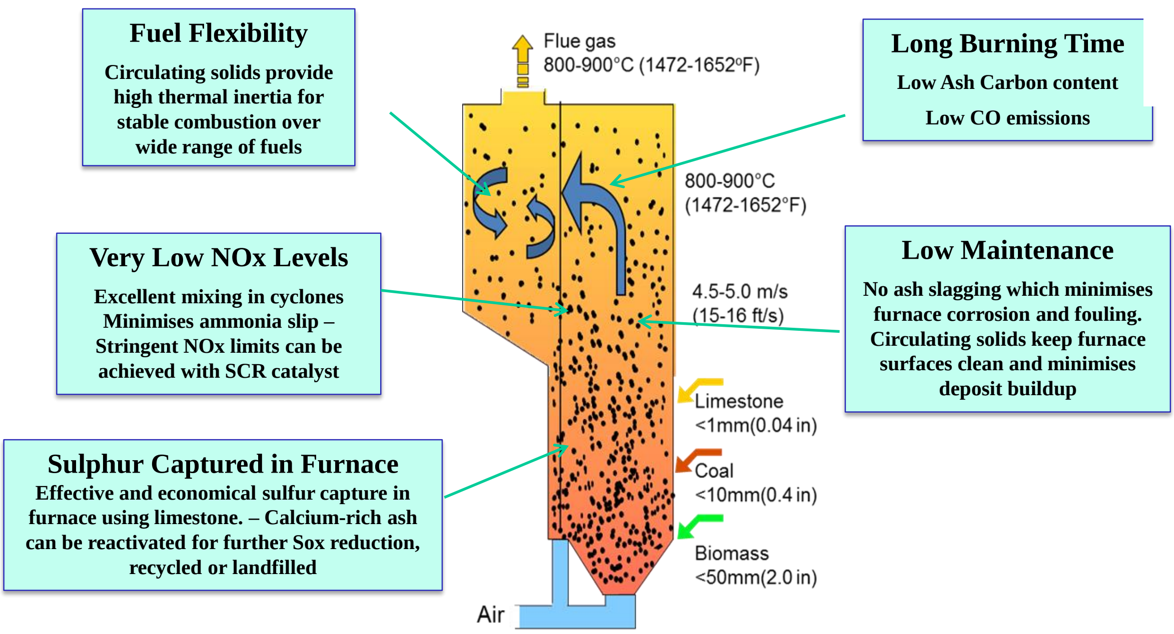
Figure 3.1 shows a conceptual image of a CFB boiler.

Figure 3.1. Adaptability of Fuels for CFB Boiler



Source: Working group meeting on this project (2019).

Figure 3.2. Conceptual Image of CFB Boiler



Source: Working group meeting on this project (2019).

1.3. Coal

Type and quality

(a) Case 1
In Indonesia, coal is produced in large amounts at a wider variety. Bituminous and higher rank sub-bituminous coal are mainly exported. Lower sub-bituminous coal and lignite are used for domestic supply. The Indonesian government is promoting the use of low-rank coal as energy and coal policy, and the development and production of lignite, lowest-rank coal, has been carried out since around 2010.
Therefore, for coal in Case 1, lignite with calorific value of 2,500 kcal/kg NAR (net as received base) is selected.

(b) Case 2
In the Philippines, 13 million tons of coal are produced annually. However, half of the coal produced is exported. Most coal-fired power plants in the Philippines use imported coal from Indonesia, which is mainly sub-bituminous coal.
Therefore, for coal in Case 2, Indonesian sub-bituminous coal with calorific value of 5,000 kcal/kg NAR is selected.

Properties of these coals are shown in Table 3.1.

Table 3.1. Properties of Raw Materials

Item	Base	Case 1		Case 2	
		Lignite	EFB	Sub-bituminous	Rice Husk
Total moisture	AR wt %	51.80	50.00	23.60	12.20
Proximate analysis	AD wt %				
Fixed carbon		41.27	18.78	43.11	13.29
Volatile matter		42.37	76.80	34.11	62.71
Ash		3.30	3.22	8.78	17.60
Moisture.		13.06	1.20	14.00	6.40
(sum.)		(100.00)	(100.00)	(100.00)	(100.00)
Fuel ratio		0.97	0.24	1.26	0.21
Total Sulphur	AD wt %	0.18	0.12	0.52	0.08
Gross HV	AD kcal/kg	5,234	4,347	5,901	3,482
	AR Kcal/kg	2,902	2,200	5,242	3,266
Net HV	AD kcal/kg	4,944	4,043	5,731	3,187
	AR Kcal/kg	2,478	1,754	5,092	2,990
Ulitmate analysis	DRY wt %				
C		65.08	44.79	70.94	40.64
H		4.62	5.67	5.10	5.07
N		1.32	1.03	1.18	0.29
S		0.21	0.13	0.52	0.04
O		24.97	44.78	12.05	35.16
Cl		0.0097	0.3483		
Ash		3.79	3.26	10.21	18.80
(sum.)		(100.00)	(100.00)	(100.00)	(100.00)
Na	mg/kg	1050	168	947	432
K	mg/kg	195	10,000	212	2,115

AR: as received base
AD: air dry base

Source: Authors.

Price

Indonesian coal prices are published weekly by the Argus and Coalindo as the Indonesian Coal Index (ICI). ICI is classified into five types based on calorific value, sulphur, ash, moisture, and size. Table 3.2 shows the specification of five types of ICI; the lignite in Case 1 and the sub-bituminous coal in Case 2 correspond to ICI-5 and ICI-3, respectively.

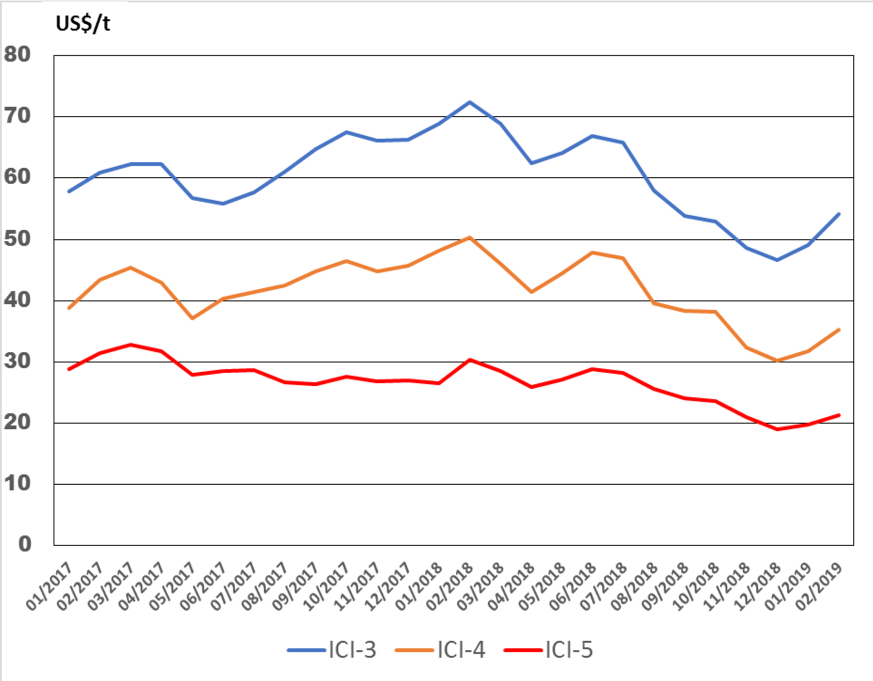
Figure 3.3 shows the price trend in the last 2 years of ICI-3, ICI-4, and ICI-5. These prices are the FOB Kalimantan in Indonesia base. Based on the price data in Figure 3.1-3, the coal price of Case 1 (Indonesia) is US$20/t and that of Case 2 (Philippines) is US$60/t, which includes US$10/t for transportation and insurance costs from Indonesia to the Philippines.

Table 3.2. Indonesian Coal Index (ICI) Specification

	Calorific Value	Sulphur, %	Ash, %	Moisture, %	Size
ICI-1	6,500 GAR/6,200 NAR	< 1	< 12	< 12	Panamax
ICI-2	5,800 GAR/5,500 NAR	< 0.8	< 10	< 18	Panamax
ICI-3	5,000 GAR/4,600 NAR	< 0.6	< 8	< 30	Panamax
ICI-4	4,200 GAR/3,800 NAR	< 0.4	< 6	< 40	Geared supramax
ICI-5	3,400 GAR/3,000 NAR	< 0.2	< 4	< 50	Geared supramax

GAR = gross as received, NAR = net as received.
Source: Argus/Coalindo (2019).

Figure 3.3. Price Trends of ICI 3, 4, 5



ICI = Indonesian Coal Index.
Source: Prepared by Authors based on Indonesian Coal Index report.

1.4. Biomass

Type and quality

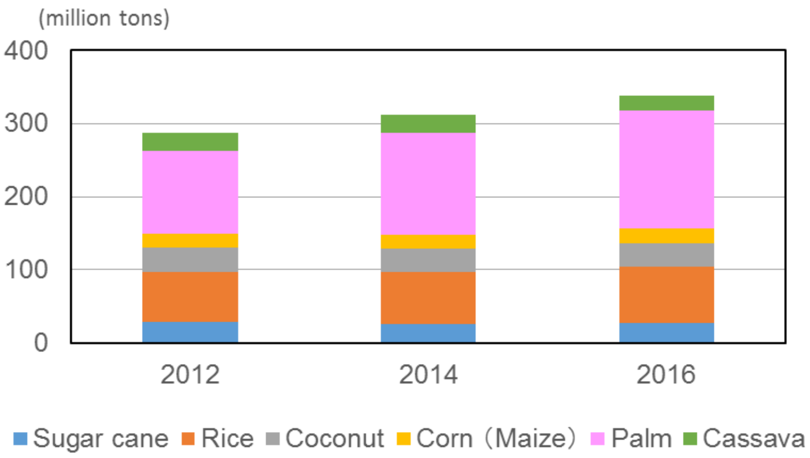
(a) Case 1

Figure 3.4 shows agricultural production in Indonesia. Palm had the largest annual production of 160 million tons in 2016. It was followed by rice (77 million tons), coconut (32 million tons), sugar cane (27 million tons), cassava (21 million tons), and corn (20 million tons).

Palm is cultivated on a large-scale plantation and is harvested and processed at a palm oil mill to produce palm oil. As described in Section 2.3, the PKS and EFB are generated as waste in palm oil mills, so that a certain amount of these wastes is

available in the market. Although the PKS is used as fuel at oil mills, it is currently traded and exported as a biomass fuel to Japan and Korea.
Therefore, for biomass in Case 1, the EFB is selected.

Figure 3.4. Agricultural Production in Indonesia



Source: FAO (2017).

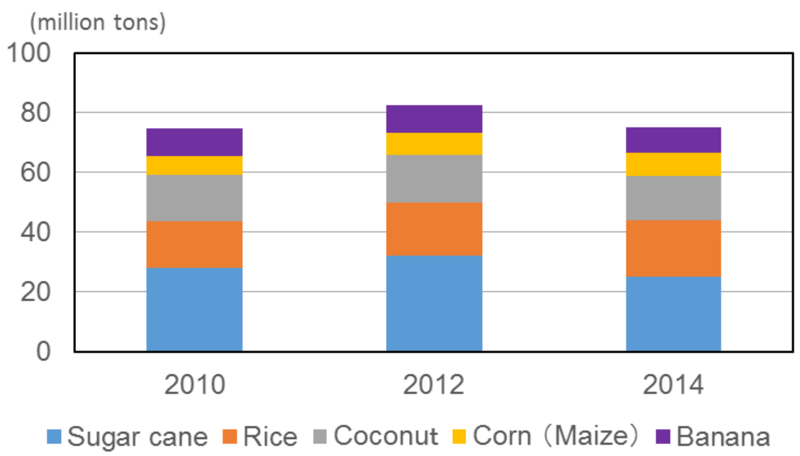
(b) Case 2

Figure 3.5 shows agricultural production in Philippines. Most produced is sugar cane at 28 million tons. This is followed by rice (19 million tons), coconut (15 million tons), and corn (8 million tons).

In the Philippines, sugar cane is already used as raw material for biofuel such as bioethanol. As mentioned, rice is the main agriculture product in other ASEAN countries. Therefore, for biomass in Case 2, rice husk, which is rice waste, is selected.

The properties of these biomass raw materials are shown in Table 3.1.

Figure 3.5. Agricultural Production in the Philippines



Source: FAO (2016).

Price

Case 1: EFB

In Indonesia, the EFB is incinerated at a palm oil mill. Since the EFB has a high potassium content resulting in incinerator ash also having a high potassium content, EFB ash after incineration is returned to the plantation to be used as fertiliser. However, incineration was banned in 2016 due to environmental issues; thus, raw EFB had to be returned to the plantation for disposal. Since the EFB is used as fertiliser in palm plantation, the palm oil mills side requested that the EFB be purchased at a price that makes up for those losses. Although the EFB disposed in plantations is effective as a fertiliser, it causes methane gas generation through corrosion and fermentation. In this case study, we assumed returning combustion ash to the plantation as fertiliser to receive free EFB.

EFB transport cost is IDR3,000/km・t according to previous JCOAL studies. Assuming that average distance from each palm oil mill to a power plant is 40 km, the purchase price of the EFB is IDR120,000/t and it is US$8.5 /t by conversion rate in Table 3.3.

Case 2: Rice husk

In general, rice collected from farmers are processed in the rice mill. After processing, milled rice (white rice), rice bran, and rice husk are generated. Average generation amounts of these products on the basis of rice are 70%, 10%, and 20%, respectively. Rice is often purchased in a wet state, and rice husk is burned to dry it before milling. About 30%–50% of the rice husk generated by milled rice is consumed for burning. The remaining 50%–70% of the rice husk is not used; it is dumped and awaits natural corrosion. A part of rice husk is used as cement raw material.

Since the purchase price of rice husk in the Philippines is currently ₱0.8–1.5/kg including transport cost, the price of rice husk in Case 2 is ₱1/kg on average and its price is US$19/ton by the conversion rate in Table 3.3.

1.5. Other conditions

Prerequisites of case studies are shown in Table 3.3.

Table 3.3. Prerequisites of Case Studies

	Case 1		Case 2	
Country Studied (Countries with similar status)	Indonesia (Malaysia, Thailand)		Philippines (Cambodia, Lao PDR, Myanmar, etc)	
Generation capacity	50 MW			
Operating duration	25 years			
Operating hours	8,000 hours / year			
Depreciation	15 years, Remaining value 10%			
Finance	Personal fund 30%, Loan 70% (Interest rate 10%)			
Corporate tax	25%		30%	
Exchange rate	¥110/US$, ¥0.00775/IDR		¥110/US$, ¥210/PHP	
Raw materials	Coal	Biomass	Coal	Biomass
Type	Lignite	EFB	Sub-bituminous	Rice husk
Properties	(Table 3.2)			
Price	20 US$/t	8.5 US$/t	60 US$/t	19 US$/t
Environment Standard (mg/Nm^3)				
SOx	750 (200)	( ): To be revisd in 2019	150 (Urban area) 200 (Other combustion equipment)	
NOx	750 (200)		700 (for SO2)	
PM	100 (50)		1000 (for NO2)	

Source: Authors.

2. Results and Estimation of Co-combustion

2.1. Fuel properties

Case 1

(a) Lignite

The lignite used in Case 1 is classified as high moisture and very low–quality coal. It is considered unsuitable for pulverised coal combustion boiler. On the other hand, it is possible to burn directly in CFB boilers without pre-drying. This lignite has a low risk of corrosion and can be used under high- temperature and high-pressure steam conditions. For 50 MW capacity, steam condition at 12.5MPa and 538°C (turbine inlet) is selected from an economic point of view.

(b) EFB

The EFB is a fuel that contains high moisture, high alkali metals and high chlorine, and therefore has a high risk of low molten salt corrosion. It is not recommended for direct combustion in large power plants. It is currently used in incinerator utilisation steam conditions (6Mpa and 460°C) in stoker furnace, etc. However, the generation of clinker in the furnace, ash adhesion to superheater pipe, problems such as molten salt corrosion, etc. occur. It is a fuel that has limited use due to its chemical composition. Therefore, in this study, we will consider the use of biomass in co-firing with coal.

Case 2

(a) Sub-bituminous coal

This coal is evaluated as a relatively high-quality sub-bituminous coal with low moisture content. The coal can be used in pulverised coal burning by technological advancement in equipment such as burners. The coal has a low risk of corrosion, and can be used under high-temperature, high-pressure steam conditions. For 50 MW, steam condition at 12.5 MPa and 538°C (turbine inlet) is selected from an economic viewpoint.

(b) Rice husk

Rice husk is a fuel that contains very high ash (mainly SiO_2) in biomass and contains high alkaline metals (mainly potassium). Compared to EFB, rice husk has no chlorine content and is relatively low risk in terms of corrosion. However, it is well known that low melting point ash is formed by the eutectic reaction of SiO_2 and K_2O. The risk, such as the problem of ash adhesion to the inside of the heater, is very high. The low-melting-point-ash formed from rice husk has a risk of melting even at 900°C or less, and is evaluated as a fuel that requires special consideration, such as selection of a low furnace temperature.

2.2. Steam conditions

The choice of steam conditions dictates the turbine efficiency which contributes significantly to the power generation efficiency at the power plant. In a 50 MW class power generation facility, the subcritical steam temperature is selected in view of the scale of the facility. It is generally selected as a non-reheat-type turbine from the economic viewpoint. In addition, this steam temperature selection requires the selection on the boiler side in consideration of the corrosion problem of the superheater weir and the like. In this study, it was necessary to consider the following three conditions of steam selection from the fuel risk (Table 3.4).

Table 3.4. Steam Conditions of Turbine at Selected Cases

Corrosion Risk	Turbine Steam Conditions		Boiler	Turbine Efficiency (%)	Application Example
	Pressure (MPaA)	Temperature (°C)	Feed water (°C)		
A: Low	12.7	538	250	40.22	Coal fired
B: Medium	10	510	230	38.62	Co-combustion High-quality fuel
C: High	8	480	185	36.07	Co-combustion Low-quality fuel

Source: Authors.

2.3. Efficiency and CO_2 reduction

Based on the consideration of fuel conditions, co-firing combustion was studied by changing the mixing ratio of biomass to coal in each of the case. The evaluations are as follows.

Efficiency

(a) Case 1
Used coal is lignite and very low quality – high moisture (51%) and low calorific value (2,478 kcal/kg NAR). Gross heat rate at coal-only fired plant is 35.3 % (low heating value [LHV]), which is a relatively good value. Although EFB as biomass also has a low quality, the gross heat rate efficiency is 34.1% at a biomass mixing rate of 25%, and 32% at a mixing rate of 50%. The decrease in efficiency is not so significant.

(b) Case 2
The results of Case 2 tend to be similar to Case 1. At coal-only fired plant, gross heat rate is 38% (LHV). Although the efficiency gradually decreases by the increase of the biomass mixing ratio, the result is as good as 32% even for biomass-only combustion. Since the raw material of Case 2 is of higher quality than Case 1, the gross heat rate and CO_2 reduction are better than Case 1.

CO_2 emission

CO_2 emission and CO_2 emission intensity in coal-fired power plants are 54.6 tons/year and 1,092 CO_2-g/kWh in Case 1, and 46.7 tons/year and 934 CO_2-g/kWh in Case 2. Since the raw materials used in Case 2 have better quality than those of Case 1, CO_2 emission and CO_2 emission intensity are lower than Case 1.

CO_2 emission is reduced by mixing biomass to coal. In Case 1, CO_2 emissions will be reduced by 81,600 tons annually if biomass is mixed with coal by 25%, and 191,200 tons annually if biomass is mixed with coal by 50%. In Case 2, CO_2 emissions will be reduced by 45,600 tons annually if biomass is mixed with coal by 25%, and 146,400 tons annually if biomass is mixed with coal by 50%.

Figure 3.6 shows the effect of CO_2 reduction by co-combustion compared to the USC and LNG power plants.

When the mixing ratio of biomass to coal is 25%, CO_2 emission intensity decreases from 1,092 to 887 CO_2-g/kWh in Case 1, and from 934 to 700 CO_2-g/kWh in Case 2. Therefore, CO_2 emission intensity is less than the USC at biomass mixing ratio of 20% (Case 2) and 30% (Case1). Additionally, at biomass mixing ratio of 50% in Case 2, CO_2 emission intensity is 486 CO_2-g/kWh, which is equivalent to LNG power plants. As a result, the co-combustion of biomass with coal clearly largely affects CO_2 reduction.

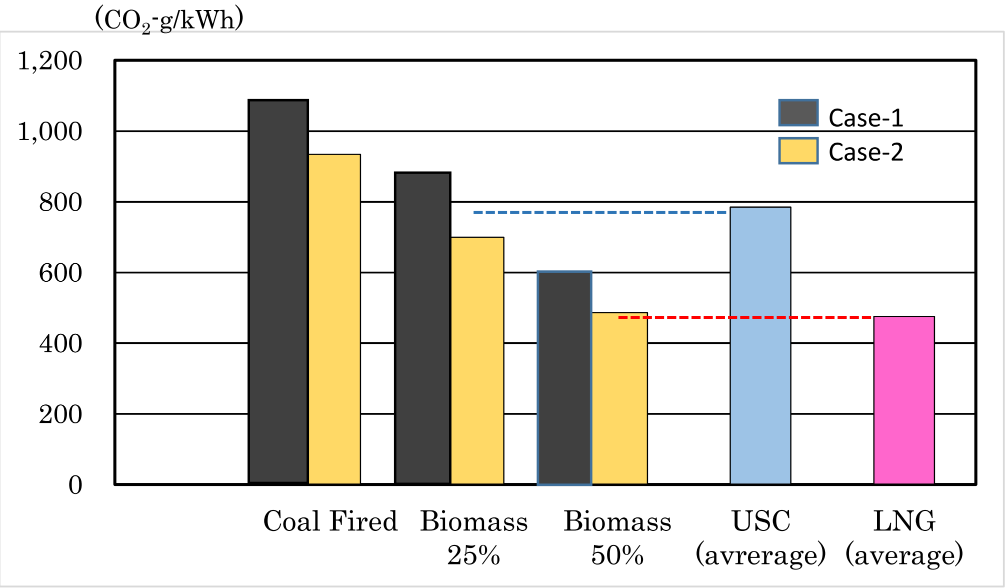
Table 3.5. Evaluation Results of Case Studies

Case 1						
Mixing ratio of raw material* (%)	Coal	100	75	50	25	0
	Biomass	0	25	50	75	100
Feed rate (t/h)	Coal	48	39	27	Not recommended	
	EFB	0	28	37		
Steam temperature (℃)		538	510	480		
Efficiency**						
Turbine (%)		40.0	38.5	36.0		
Boiler (%, LHV)		89.2	89.4	89.7		
Gross heat rate (%, LHV)		35.3	34.1	32.0		
CO_2 emission						
CO_2 amount (ton/hr)		54.6	44.4	30.7		
CO_2 intensity (g/kWh)		1,092	887	614		
CO_2 reduction (ton/year)		—	▲81,600	▲191,200		

Case 2						
Mixing ratio of raw material* (%)	Coal	100	75	50	25	0
	Biomass	0	25	50	75	100
Feed rate (t/h)	Coal	24	18	12.5	6.5	0
	Rice husk	0	10	21	33	44
Steam temperature (℃)		538	538	510	480	480
Efficiency**						
Turbine (%)		40.0	40	38.5	36	36
Boiler (%, LHV)		90.8	91.0	91.2	91.4	91.6
Gross heat rate (%, LHV)		36.0	36.0	34.8	32.6	32.6
CO_2 emission						
CO_2 amount (ton/hr)		46.7	41.0	28.4	14.8	0
CO_2 intensity (g/kWh)		934	700	486	252	0
CO_2 reduction (ton/year)		—	▲45,600	▲146,400	▲252,200	▲373,600

* Calorific value base.
**Transmission efficiency of 99%.
Source: Authors.

Figure 3.6. Effect of CO_2 Reduction by Co-combustion



Source: Authors.

2.4. Economic evaluation

Economic evaluation was considered under the following two conditions.

- IRR (internal rate of return) at tariff of US ¢ 8 /kWh
- Tariff at IRR of 10%

According to data published by the Ministry of Energy and Mineral Resources of Indonesia, the average power generation cost in Indonesia in 2018 was US ¢ 7.86/kWh, and average power generation cost in East Kalimantan province, which has many coal mines and palm plantations, is US ¢ 10.58/kWh. In addition, the power generation cost of coal-fired power plants in the Philippines is US ¢ 6.03–11.95 /kWh. From these data, we set US ¢ 8 as tariff.

Tariff is assumed at IRR 10%, which is generally the minimum rate that makes a project economically viable.

Economic evaluation results of co-combustion based on prerequisites indicated in Table 3.5 are shown in Table 3.6.

In either case, with tariff at US ¢ 8, project profit cannot be gained because of negative IRR. The tariff that may sustain IRR at 10% is US ¢ 15–16/kWh, which is much higher than the prevailing prices.

Therefore, among the preconditions for evaluation, the economics at loan interest rate of 5% were considered. Table 3.7 shows the effect of loan interest rate.

The IRR was negative even if the interest rate was 5%. Tariff slightly improved but the selling price remained high.

Large USC coal-fired power plants require high capital cost, while generation cost is less than US ¢ 10/kWh because of high generation efficiency of 40% or more.

In this case, higher selling price may be inevitable with low generation efficiency due to the poor quality of raw materials. Also, economies of scale do not hold due to the small capacity of power plants.

Thus, to establish a business, it is necessary to consider incentives for CO_2 reduction effects comparable to the USC and LNG, in addition to funds with low interest rates.

Table 3.6. Economic Evaluation Results of Case Studies

Case 1						
Mixing ratio of raw materials (%)	Coal	100	75	50	25	0
	Biomass	0	25	50	75	100
Efficiency						
Gross heat rate (%, LHV)		35.3	34.1	32.0		
CO_2 emission						
CO_2 intensity (g/kWh)		1,092	887	614		
CO_2 reduction (ton/year)		—	▲81,600	▲191,200		
Economic analysis						
IRR at US ¢ 8/kWh –tariff (%)		-2.0	-1.7	-1.5		
Tariff at 10% -IRR (US ¢ /kWh)		15.4	15.3	15.2		

Case 2						
Mixing ratio of raw materials (%)	Coal	100	75	50	25	0
	Biomass	0	25	50	75	100
Efficiency						
Gross heat rate (%, LHV)		36.0	36.0	34.8	32.6	32.6
CO_2 emission						
CO_2 intensity (g/kWh)		934	700	486	252	0
CO_2 reduction (ton/year)		—	▲45,600	▲146,400	▲252,200	▲373,600
Economic analysis						
IRR at US ¢ 8/kWh –tariff (%)		-7.3	-6.0	-4.6	-3.8	-2.0
Tariff at 10% -IRR (US ¢ /kWh)		16.8	16.6	16.3	16.1	15.5

IRR = internal rate of return, LHV = low heating value.
Source: Authors.

Table 3.7. Effect of Loan Interest Rate

Case 1							
Mixing ratio of raw materials (%)		Coal	100	75	50	25	0
		Biomass	0	25	50	75	100
Economic analysis							
Interest rate	10 %	IRR at US ¢ 8/kWh –tariff (%)	-2.0	-1.7	-1.5		
		Tariff at 10% -IRR (US ¢ /kWh)	15.4	15.3	15.2		
	5 %	IRR at 8 ¢ /kWh –tariff (%)	-1.6	-1.3	-1.1		
		Tariff at 10% -IRR (US ¢ /kWh)	13.9	13.8	13.7		

Case 2							
Mixing ratio of raw materials (%)		Coal	100	75	50	25	0
		Biomass	0	25	50	75	100
Economic analysis							
Interest rate	10 %	IRR at US ¢ 8/kWh –tariff (%)	-7.3	-6.0	-4.6	-3.8	-2.0
		Tariff at 10% -IRR (US ¢ /kWh)	16.8	16.6	16.3	16.1	15.5
	5 %	IRR at US ¢ 8/kWh –tariff (%)	-6.8	-5.5	-4.1	-3.4	-1.6
		Tariff at 10% -IRR (US ¢ /kWh)	15.2	15.0	14.7	14.5	13.9

IRR = internal rate of return.
Source: Authors.