Viability study on cofiring technology of agricultural waste and coal for air pollution control in India

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Central Electricity Authority of India (CEA)
New Energy and Industrial Technology Development Organization (NEDO)
Japan Coal Energy Center (JCOAL)

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List of Acronyms

CEA :Central Electricity Authority of India
NEDO :New Energy and Industrial Technology Development Organization
JCOAL :Japan Coal Energy Center
GOI :Government of India
GHG :Green House Gas
NTPC :NTPC Limited
NCR :National Capital Region
CERC : Central Electricity Regulatory Commission
TGA :Thermogravimetric Analysis
PSPCL :Punjab State Power Corporation Limited
GNDTP :Guru Nanak Dev Thermal Plant
GHTP :Guru Hargobind Thermal Plant
PLF :Plant Load Factor

Annexure

Executive Summary

GOI is considering the massive installation of renewables and utilization of biomass to coal-fired power stations as a practical measure of GHG mitigation as well as environmental impact. Another issue of Another issue of air quality deterioration in NCR Delhi by open-burning of agricultural waste from surrounding states become a pressing issue, especially in the winter season. Since Punjab, Haryana, and Uttar Pradesh located in the north of NCR Delhi are the main food supply area to the capital, open-burning of agricultural waste is historically implemented to recover their crop field.

As the preliminary, the survey of the agricultural waste situation was conducted to estimating the potential for biomass cofiring utilization. Analysis of rice husk as potential waste was also conducted. Through the communication with SEA, 3 states, Uttar Pradesh, Punjab, and Haryana were selected for a statistical survey for the reason that these 3 states located in the north of Delhi.

Punjab State was found to be most suitable for further study from the viewpoint of biomass potential.

Through the site survey at GNDTP and GHTP in PSPCL, Data was collected to estimate to generation cost of biomass and coal cofiring at the existing coal-fired power station. Information regarding the paddy straw for cofiring is also collected. As a result, the installation of biomass pelletizing technology is found to be the most feasible. Its generation cost is expected to roughly equal to the current generation cost of GHTP. Other issues to be considered were described.

The plan of Installation of pelletizer to FTP without any modification of current facilities is estimated to be most feasible for cofiring at GHTP. Its conclusion is summarized in the table.

	Plan	Content	Fuel cost (Rs / kWh)	Biomass ratio (cal.%)	Capital cost (Cr Rs)	Generation cost (Rs / kWh)
Reference	Current	GHTP 250 MW	3.50	-	-	5.54
Proposal	Pelletizer	GHTP 250 MW	3.25	30	110	5.54

Depreciation of pelletizer: 7 years

The materialization of agricultural waste utilization an urgent issue in India not only protect air quality but also a practical measure of GHG mitigation. Demonstration project might be a better way prior to the installation of a commercial plant. Both sides have to consider an appropriate budget to conduct this demonstration.

The study team will be happy that this report will be submitted to MOP by CEA for further consideration of biomass utilisation policy in India power sector to mitigate GHG.

1. Background

While coal is a mainstay of the primary energy of India as an affordable and reliable domestic energy source, its higher CO_2 emission is not suitable for the global decarbonization trend. In this regard, GOI is considering the massive installation of renewables and utilization of biomass to coal-fired power stations as a practical measure of GHG mitigation as well as environmental impact. NTPC already plans to utilize agricultural waste pellet at NTPC owned Thermal Power Stations and surrounded areas.

Air quality deterioration in NCR Delhi by open-burning of agricultural waste from surrounding states become a pressing issue, especially in the winter season. Since Punjab, Haryana, and Uttar Pradesh located in the north of NCR Delhi are the main food supply area to the capital, open-burning of agricultural waste is historically implemented to recover their crop field.

Figure 1-1 Photos from news web

In this connection, the following discussion has made as bilateral collaboration topics in the meeting of the Joint Working Group on Electricity and Renewable Energy under the India-Japan Energy Dialogue held on Jan. 24, 2018.

1) Cofiring of biomass with higher blending ratios.
2) Conversion of pulverized fuel-fired plants to 100% biomass firing or 100% biomass-based fuels in Japan.
3) Generating energy from Municipal Waste.

In the same year, comprehensive and technical presentation and discussion have aggressively done during CEA-JCOAL workshop on Nov. 16, 2018. Through this discussion, it was found that agricultural waste such as wheat, paddy, sugarcane is the main source as biomass energy. In this regard, this study will first survey the statistical potential of agricultural waste for focusing on a specific and detailed study.

2. Preliminary Study

The preliminary study aimed to provide the Information by communicating with the nodal points in India end for identifying the issues and barriers to be addressed for expediting biomass utilization. Especially, the survey of the agricultural waste situation was conducted as a potential for biomass cofiring utilization. Analysis of rice husk as potential waste was also conducted. During the communication with SEA, 3 states, Uttar Pradesh, Punjab, and Haryana were selected for a statistical survey for the reason that these 3 states located in the north of Delhi.

2.1. Agricultural Statistics of Punjab, Haryana and Uttar Pradesh

Punjab, Haryana and Uttar Pradesh were selected for this preliminary study. Statistical data as their biomass potential for cofiring with coal at the coal-fired power station located in the same area are collected and analyzed as follows.

Table 2-1 Agricultural production and waste potential in Punjab

Crop	Products			Agricultural Waste	
	Area	Yield	Production	residue	generation
	ha	kg/ha	tonne/y		tonne/y
paddy	2,710,000	5,970	16,179,000	duck, hask	56,102,400
wheat	3,500,000	4,714	16,500,000	stalk, sheath	28,938,600
sugarcane	100,000	75,000	7,500,000	bagasse, leaves	2,707,500
cotton	500,000	600	300,050	fruit, stalk	1,707,628
maize	200,000	3,600	720,000	cob, stalk	949,900
rapeseed	45,000	1,289	58,000	stalk	92,880
guara	33,300	862	28,700	stalk	66,800
bearly	1,200	3,667	44,000	stalk	43,290
peas	4,000	1,350	5,400	stalk	26,500
sumflower	20,000	1,800	36,000	stalk	24,600
arhar	5,700	822	4,700	shell, stalk	7,280
gram	3,000	1,300	3,900	stalk	2,420
urad	2,100	501	1,100	shell, stalk	1,430
lentis	1,600	750	1,200	stalk	720
groundnut	3,000	1,800	5,100	stalk, leaves	700
bajura	1,000	580	1,000	core, shell,stalk	0
total	7,129,900		41,388,150		90,672,648
current utilization (%)					56
potential waste to be utilized(tonne/y)					39,895,965

Source: Agricultural Dept. of Punjab (2016-17)

Punjab (the five rivers region) is one of the most fertile regions on earth. The region is ideal for growing wheat crop. Rice, sugar cane, fruits and vegetables are also grown. Punjab is called the "Granary of India" or "India's bread-basket." Many records mistakenly mention that it produces 43% of India's wheat, but that is actually its contribution to the national pool. It produces 17% of India's wheat, and 11% of India's rice (2013 data). The total area of Punjab is just 1.4% of total area of India, but it produces roughly 12% of the cereals produced in the country.

Table 2-2 Agricultural production and waste potential in Haryana

Crop	Products			Agricultural Waste	
	Area	Yield	Production	residue	generation
	ha	kg/ha	tonne/y		tonne/y
wheat	2,558,000	4,841	1,238,400	stalk, sheath	22,291,200
paddy	1,386,000	3,213	4,453,000	duck, hask	14,249,600
cotton	570,000	609	2,041,000	fruit, stalk	6,656,200
sugarcane	102,000	80,164	8,223,000	bagasse, leaves	3,124,740
bajura	478,000	2,017	964,000	core, shell,stalk	2,535,320
rapeseed	526,700	1,853	959,800	stalk	1,936,000
guara	315,000	787	248,000	stalk	496,000
bearly	20,000	3,658	73,000	stalk	94,900
jowar	62,000	533	33,000	stalk	79,200
gram	37,000	1,179	44,000	stalk	48,400
peas	48,000	667	32,000	stalk	41,600
maize	5,000	3,400	17,000	fruit, stalk	39,100
moong	20,000	852	17,000	fruit, stalk	21,150
total	6,127,700		18,343,200		51,613,410
current utilization (%)					40
potential waste to be utilized(tonne/y)					30,968,046

Source: Agricultural Dept. of Haryana (2016-17)

Haryana state is considered as one of the agricultural states of India. The state has a geographical area of about 44,200 km2, which is 1.4% of the total geographical area of the country. About 85% of the area in the state is cultivable, of which 96% has already been brought under plough. Out of the total ploughed area, 75% is cultivated area; 50% is irrigated through groundwater, and the rest is from the surface water such as canals, drains and rivers. About 70% of the total population is sustained on agriculture, and thus, agriculture is the main economic activity in the state.

Round the year, different varieties of crops are grown in the state. The major crops grown during the rabi season are wheat, barley, gram, mustard, cotton and sugarcane, while during kharif season paddy, jowar, bajra and maize. The residues generated from these crops consists of wheat stalk and pod, barley stalk, gram stalk, mustard stalk and husk, cotton stalk, sugarcane top and trash, paddy husk and straw, jowar stalk, bajra stalk and cobs and maize stalk and cobs. Apart from these major and minor crops, there are various other crops such as chilies, vegetables, pulses, and green manure etc.

Based on ecology and cropping pattern, the state is delineated (as below figure) into the following three zones. These zones have their own strength and weaknesses. Accordingly, the farming systems and cropping systems have emerged.

Table 2-3 Agricultural production and waste potential in Uttar Pradesh

Crop	Products			Agricultural Waste	
	Area	Yield	Production	residue	generation
	ha	kg/ha	tonne/y		tonne/y
sugarcane	2,160,000	72,662	156,949,000	bagasse, leaves	55,415,800
paddy	5,992,000	2,415	14,470,000	duck, hask	44,288,000
wheat	9,885,000	3,538	34,971,000	stalk, sheath	36,657,000
groundnut	576,000	24,231	13,957,000	stalk, leaves	10,461,960
bajra	907,000	1,914	1,736,000	core, shell,stalk	4,847,100
bearly	170,000	2,706	460,000	stalk	3,289,000
maize	794,000	1,878	1,491,000	cob, stalk	2,932,500
rapeseed	1,079,000	950	1,025,000	stalk	1,736,000
arhar	338,000	1,074	363,000	husk, stalk	467,600
urad	595,000	539	321,000	shell, stalk	396,500
gram	562,000	1,114	626,000	stalk	187,000
peas	384,000	1,378	529,000	stalk	149,500
moong	44,000	409	18,000	cob, stalk	56,250
cotton	6,000	333	2,000	fruit, stalk	33,200
onion	23,000	13,913	320,000	stalk	15,250
total	23,515,000		227,238,000		160,932,660
current utilization (%)					78
potential waste to be utilized(tonne/y)					35,405,185

Source: Agricultural Dept. of Uttar Pradesh (2016-17)

Uttar Pradesh with a total area of 24.09 million hectare is India’s fifth largest state in terms of land area. The state has both a large population and a high population growth rate. It is the most populous state in India, with a population of 199.5 million as of 1 March 2011. The population density is 828 people per square kilometer, making it one of the most densely populated states in the country. During the decade from 1991 to 2001 its population increased by over 25.8%. Agriculture is the leading occupation in Uttar Pradesh. Wheat is the state's principal food crop and sugarcane is the main commercial crop.

As per the Central Electricity Regulatory Commission (CERC) norms for Biomass based power plants, the station heat rate for biomass power projects shall be:

a) For projects using travelling grate boilers: 4200 kCal/kWh

b) For projects using AFBC boilers: 4125 kCal/ kWh

And the calorific value of the biomass fuel used for the purpose of determination of tariff shall be at 3100 kCal/kg. For the purpose of this report, the worst case i.e., heat rate of 4200 kcal/kWh and GCV of 3100 kcal/kg has been considered. Considering the above, the specific fuel consumption of a biomass plant comes to 1.35 kg/kWh. According to these assumptions, potential capacity from agricultural waste utilization is shown in Table 2-4. Punjab State was found to be most suitable for further study from the viewpoint of biomass potential.

Table 2-4 Biomass Waste and Potential Capacity

State	Biomass Waste Potential (tonne/y)	Potential Capacity (MW)
Punjab	39,895,965	3,373
Haryana	30,968.046	1,746
Uttar Pradesh	35,405,185	2,957

2.2. Analysis of Rice Husk Sample

Rice husk was obtained from the rice husk accumulation site in Haryana for biomass sample analysis. Moisture, ash, volatile matter, fixed carbon of rice husk sample was measured by thermogravimetric analysis (TGA, ULVAC TGD-7000) in N_2 atmosphere and 10 degC/min heating rate. Ultimate analysis of rice husk was done by CHN multi-analyzer. Ash components in rice husk were measured by X-ray Fluorescence analyzer (Shimadzu EDX-700). Thermal decomposition behavior of rice husk was analyzed using TGA during RT to 1000 degC.

Table 2-5 Proximate analysis (wt. %)

V.M.	F.C.	Ash	Moisture
59.9	22.6	11.2	6.3

Table 2-6 Ultimate analysis (wt.%, daf)

Carbon	Hydrogen	Oxygen (diff.)	Nitrogen
47.2	6.1	46.7	–

Table 2-7 Ash component analysis (wt. %)

Si	K	S	Ca	other
77.1	14.4	3.8	3.6	1.0

Rice husk contains 11 wt.% of ash with the main element of Si. Volatile matter, fixed carbon and moisture were 59.9%, 22.6% and 6.3%, respectively. In the organic portion, no heteroatom such as S and N contain in rice husk. This seems to be an advantage for flue gas impact to air quality.

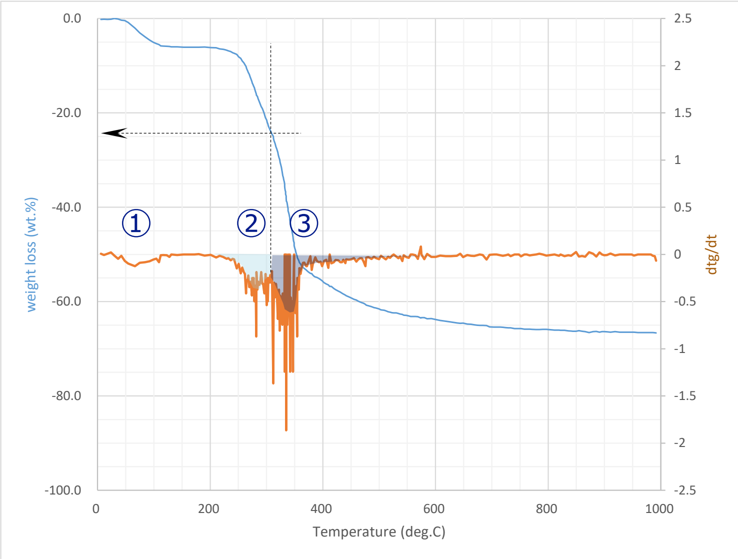


Figure 2-1 Thermal decomposition behavior of rice husk

Three typical change in weight was observed during the TG analysis shown in Figure 2-1,

(1) < 100 degC; evaporation of moisture,

(2) 250-300 degC; decomposition of H_2O from cellulose,

(3) 300 degC<; thermal decomposition of cellulose,

In the case that the torrefaction process will be applied to rice husk, under 300 degC treatment is recommended to keep calorie. Weight loss of torrefaction treatment is approximately 25%.

2.3. Potential Cofiring Technology

There are several coal-fired power plants in japan which were specially designed for high biomass mixing ratio. Biomass/coal separate fuel supply system combined with cofiring in the boiler allows a high blend ratio of 30 % calorie base (Figure 2-2). This system is commercially available in Japan.

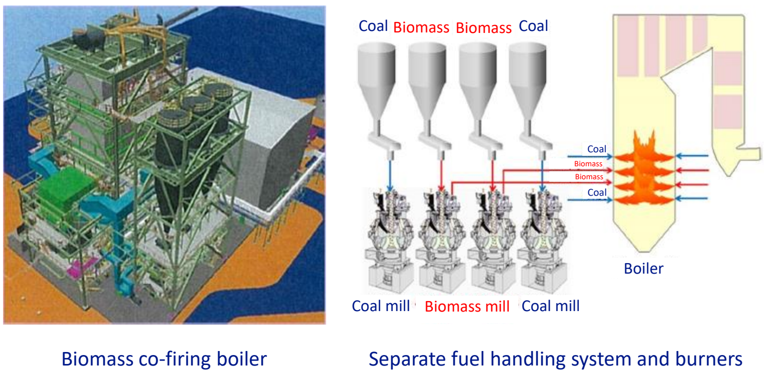


Figure 2-2 Biomass/coal separate fuel supply system

Source: MHPS technical report (2017)

3. Site Survey of the Target Plants in PSPCL

Preliminary Study on Biomass Cofiring with Coal was conducted in FY2018 for three candidate states, Punjab, Haryana and Uttar Pradesh to estimate their agricultural waste potential for utilized biomass fuel. Resource analysis revealed that Punjab has the highest potential capacity for agricultural waste utilization and Punjab State Power Corporation Limited (PSPCL) also expressed interest in our survey. Under the discussion of the importance of this study in the electricity working group of India-Japan Energy Dialogue as effective measures to mitigate GHG in India, JCOAL had, therefore, conducted a viability study as a follow-up survey in FY2019, the applicability of commercialized biomass cofiring technology in Punjab.

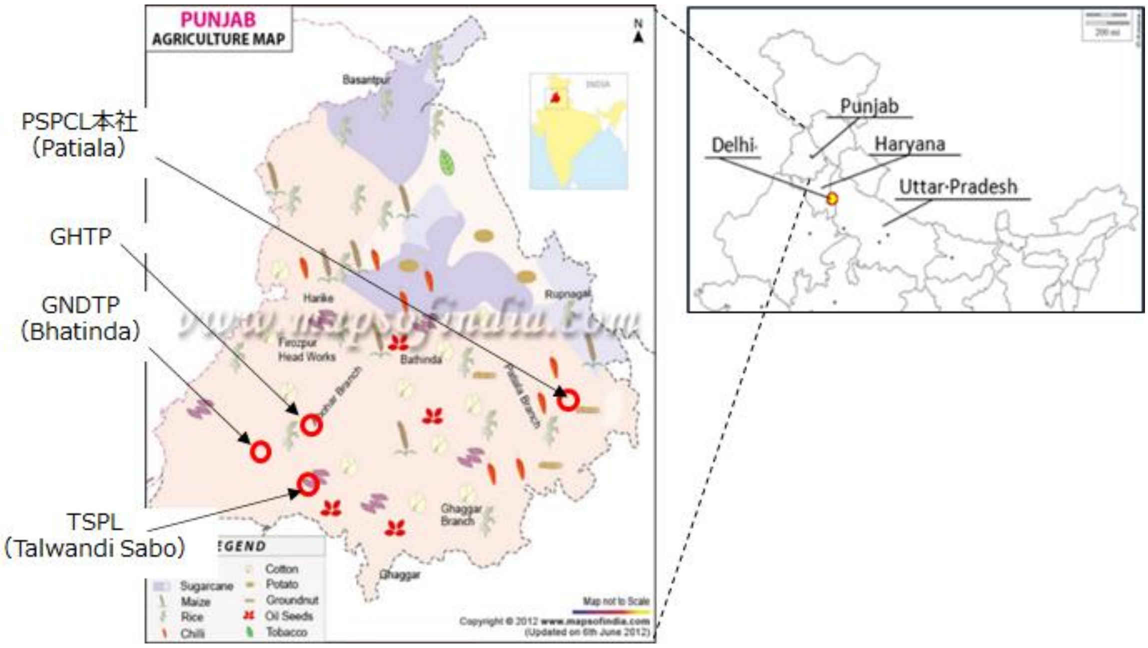


Figure 3-1 Coal-fired power plants in Punjab state

3.1. Justification

1) Basic policy on biomass cofiring in PSPCL

PSPCL has three coal-fired power plants with total output of 2,640 MW. Among these, GNDTP (Guru Nanak Dev Thermal Plant: 2×110 MW+2×120 MW), classified in a small capacity, has been shut down without a deadline since January 2018, because of the following reasons.

- ✓ The fuel cost is high because the using coal was transported over 2,000 km from the eastern state.
- ✓ The long-term purchase contract (coal linkage) has been canceled and it will take time to recover.
- ✓ Large-scale power plant TSPL (3×660MW) near GNDTP caused losing cost competitiveness.

In addition, GNDTP has proposed to the state department to replace existing units with 60 MW (2×30 MW) paddy straw burning plant, but it has not been approved. In that case, the existing boilers will be rebuilt for firing biomass, only paddy straw to be purchased from nearby vendors.

Because in 2014 GNDTP invested in a remodeling project for distributed control of 120MW Units 3 and 4, they hope to resume coal-fired operation.

JCOAL proposed 30% cofiring as a method to maximize the use of existing facilities, considering the amount of biomass that can be supplied. GNDTP is considering refurbishment of equipment using a biomass burning plan, but it is worth considering for them if the cofiring plan is economically advantageous.

There is another operating power plant (GHTP: Guru Hargobind Thermal Plant: 2×210MW+2×250 MW) owned by PSPCL, and it is possible to carry out biomass cofiring at this power plant. PSPCL and officials of two power plants (GNDTP/GHTP) have promised full cooperation for this study.

2) Information on agricultural waste in Punjab (type, quantity, collection, transportation, etc.)

Type : Available agricultural waste is mostly paddy straw, and a little wheat and other.

Volume : Equivalent to 2,200MW per year (16.5 million tons/y of agricultural residue) throughout the state. 60MW/y (450,000 tons/y of paddy straw) equivalent around the target power plant

Collection/Transportation: Biomass will be purchased from the local companies that collect and sell biomass.

3.2. Site Survey at GNDTP

JCOAL conducted the preliminary follow-up survey at GNDTP during 10-14 December 2019. The units started operation in 1974-79. All the units were renovated for modernization, Units 1 and 2 in 2006-7 and Units 3 and 4 in 2012-14.

Boiler : A corner firing type boiler with four-stage tilting burners. Units 1 and 2 are renovated by BHEL, and units 3 and 4 by ALSTOM. There found not much aging in appearance.

Coal storage: Eastern coal transported by freight wagons is received by a dispenser, stored in a coal storage yard by bulldozers and transported to a boiler on a conveyor. The maximum amount of coal received is 7,400 Ton / day for four units.

Mills : 4 horizontal ball mills for 1 boiler, 3 in service (1 spare). The pulverized coal is sent to burners by four pulverized coal pipes from each mill and burned in a furnace.

Units 1 and 2 are old-style indirect combustion systems, while Units 3 and 4 have been remodeled to new-style direct combustion systems, making them state-of-the-art facilities.

Figure 3-2 GNDTP

3.3. Site Survey at GHTP

Considering the current situation of GNDTP and the effectiveness of biomass cofiring, further study was conducted at GHTP, which is the larger coal-fired power plant operated by PSPCL.

Based on the results of the preliminary survey, a secondary survey targeting GHTP was conducted on 3-7 February 2020.

(1) Information of biomass

- ✓ The main source of biomass in Punjab is paddy (rice), "rice husk" and "paddy straw". Rice husk is used for livestock food and paper manufacturing and is not generally available on the market. On the other hand, “paddy straw” is left on the paddy field and incinerated causing a smog trouble in the autumn in the vicinity of Delhi.
- ✓ It is expected to be very effective if paddy straw can be used as a fuel for cofiring in boilers for coal-fired power plant, it will provide a foothold for effective use of biomass under government policy.

(2) Unit information

There are a total of 4 coal-fired units supplied by BHEL. The layout of the unit and main facilities are shown in Figure 3-3. The operation performances are listed in Table 3-1.

- ✓ Stage I: Unit 1&2 (2×210MW, Start operation in 1999)
- ✓ Stage II: Unit 3&4 (2×250MW, Start operation in 2008 and 2010)
- ✓ Steam generator: Reheat-type natural circulation, corner firing boiler with 4-stage tilting burners.
- ✓ Electrostatic precipitator (ESP)is installed.
- ✓ Coal firing system: 4 vertical bowl mills /1 boiler, 3 regular use (1spare). The pulverized coal is sent to the burners through four pulverized fuel pipes from each mill and burned in the furnace.
- ✓ Condenser cooling: Cooling towers are located beside the reservoir.
- ✓ Coal handling and storage system: Bituminous coal transported by freight car from the Gondwana coalfield in eastern India, received by a wagon tippler, stored in a coal yard by stacker reclaimers

and transported by conveyors to boilers. The transfer capacity of the conveyor is 1,000 Tons / day for both Stage I and II.

Figure 3-3 Unit layout and main facilities of GHTP

Table 3-1 The operation performances of GHTP

Item		GHTP	
		Unit 1&2	Unit 3&4
Capacity	MW	210 X 2	250 X 2
Rated steam flow	T/h	627.3 (TMCR) /unit	741 (TMCR) /unit
Steam. Press. x Temp.	Kg/cm^{2}x°C	155x540	155x540
Design Heat Rate	Kcal/kWh	2272	2241
Heating Value of Coal (GCV)	Kcal/kg	3982	3982
Present Coal Price	Rs/Ton	5233	5233
Present Generation Cost	Rs/kWh	5.9* (Variable cost 3.5** + Fixed cost 2.4) ** coal cost approx. 3.5	

Coal used in GHTP has high ash content as shown in Table 3-2. Paddy straw has calorific value, about 81% of coal but high amount of silica SiO_2 and 6-8% alkali content in combustion ash.

Table 3-2 Coal and Paddy straw characteristics

Item / Content		Coal	Paddy Straw
Fixed carbon	%	28.4	14.3
Volatile matter	%	23.7	48.2
Ash	%	33.8	21.8
Moisture	%	14.1	15.7
Heating Value (GCV)	Kcal/kg	3982	3239
Alkali (K,Na)	%	-	6 - 8

(3) Interviews with the biomass suppliers and their facility surveys

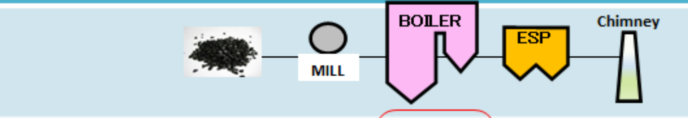
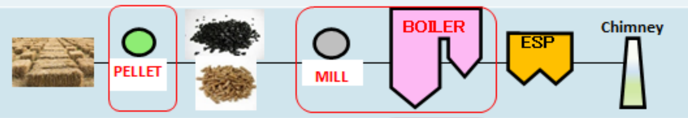
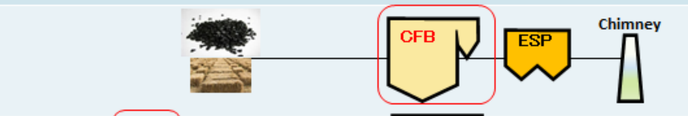
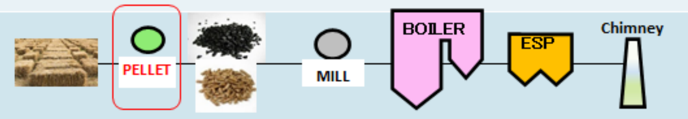
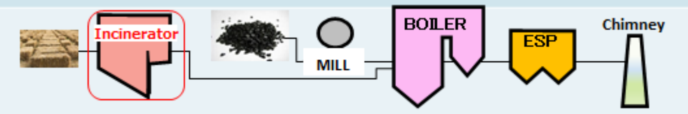
JCOAL visited Farm2Energy and Zamindara Farmsolutions for interview and survey. Paddy straw is handled as the bale shown in Figure 3-4. Information obtained in the interview with the biomass suppliers is shown in Annexure.

Figure 3-4 Handling process of Paddy straw

3.4. Proposed cofiring technologies

Proposed cofiring plans are listed in Table 3-3. Ref-1 and Ref-2 are a current condition and PSPCL's Plan of biomass firing, respectively. Plan-1 to Plan-4 are the proposed technologies and their capital investment is required for the equipment surrounded by a red line frame in Table 3-3.

Table 3-3 Plans of cofiring to be considered

No.	Plan	Basic flow
Ref-1	Existing	
Ref-2	Biomass boiler introduced (PSPCL plan)	
Plan-1	Biomass mixing system introduced	
Plan-2	Fluidized bed boiler introduced	
Plan-3	Introduced paddy straw pelletizing equipment + existing unit	
Plan-4	Paddy straw gasification melting furnace + existing unit	

Plan-1: Modification of a boiler, the addition of biomass mill, and pelletizing facility for high mixing ratio. The same process is SOMA Energy park Coal-fired boiler supplied by MHPS, Japan (112MW with 30% biomass) shown in Figure 3-5.

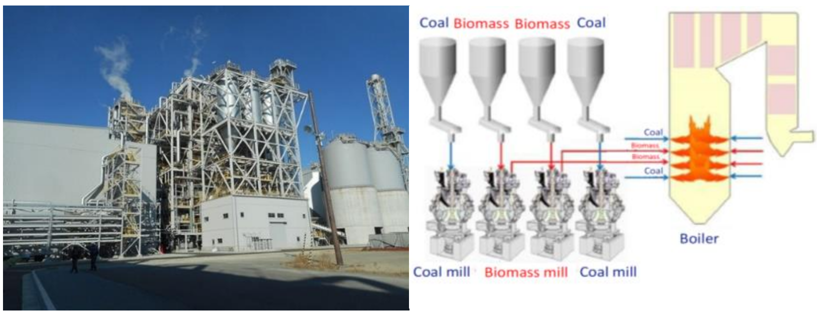


Figure 3-5 Plan 1 (Biomass mixing system: different mills are required)

Source: https://power.mhi.com/news/20180821.html

Plan-2: Replacing existing PC boiler to CFB boiler. The same process is HOFU biomass co-firing CFB unit supplied by SHI, Japan (112MW with 50% biomass) shown in Figure 3-6.

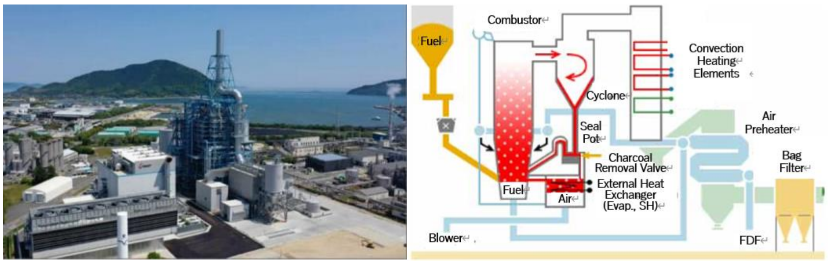


Figure 3-6 Plan 2 (Circulating Fluidized Bed boiler)

Source: https://www.energia.co.jp/e/business/int_business/skills/thermal-pg.html

Plan-3: Installing paddy straw machine shown in Figure 3-7. No modification and/or addition is required to the existing plant.

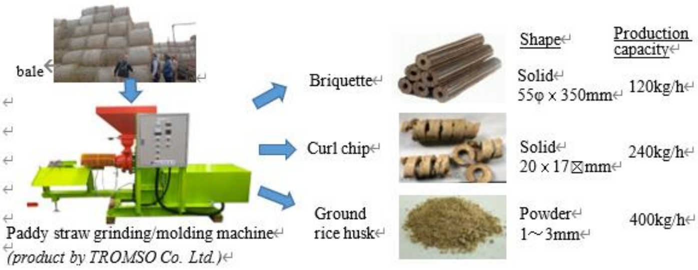


Figure 3-7 Biomass solid fuel conversion device

Source: https://tromso.co.jp/grindmill.html

Plan-4: Installing incinerator and addition of path of decomposed gas to the existing boiler shown in Figure 3-8. Modification of the combustion operation sequence will be needed if required.

Figure 3-8 Combination and generation unit for municipal waste-to-energy plant

Source: https://kinsei-s.co.jp/english/

According to the data obtained during the site survey, each plan was roughly estimated for its generation cost of both GNDTP and GHTP as shown in Table 3-4 and Table 3-5, respectively. Plan-4, installing incinerator is not estimated further because this plan requires an additional area and complicate boiler control sequences.

Table 3-4 Cost estimation of each plan at GNDTP

No.	Plan	Content	Fuel cost (Rs/kWh)	Capital investment (Cr Rs)	Power generation cost (Rs/kWh)	Task
Ref-1	Existing (shutdown)	120MW×1 (Existing)	3.27	520	3.90	Reuse not scheduled
Ref-2	Biomass boiler introduced (PSPCL plan)	30MW×2 (New unit)	2.72	175	4.00	Reuse existing TG Low efficiency expected
Plan-1	Biomass mixing system introduced	120MW×1 (Remodeling)	3.03	520	4.43	Boiler modification required Pellet supply required Linkage update required
Plan-2	Fluidized bed boiler introduced	120MW×1 (New unit)	3.03	1300	6.21	New boiler construction required Linkage update required
Plan-3	Introduced paddy straw pelletizing equipment + existing unit	120MW×1 (Existing)	3.03	65	3.41	Coordination with supplier required. Linkage update required

Table 3-5 Cost estimation of each plan at GHTP

No.	Plan	Content	Fuel cost (Rs/kWh)	Capital investment (Cr Rs)	Power generation cost (Rs/kWh)	Task
Ref-1	Existing (In service)	GHTP 250MW (Existing)	3.05	-	3.23	In operation but expensive
Plan-5	Biomass mixing system introduced	GHTP 250MW×1 (Remodeling)	2.66	870	3.78	Boiler modification required Pellet supply required
Plan-6	Fluidized bed boiler introduced	GHTP 250MW×1 (New unit)	2.73	2170	5.30	New boiler construction required
Plan-7	Pelletizer introduction + existing unit	GHTP 250MW×1 (Existing)	2.66	110	2.96	Coordination with supplier required.

Plan-7 at GHTP is obviously the most cost-competitive among the proposed plans. Plan-7 has not required any large investment and most of the existing facility can be used without any modification. In the next chapter, the cost estimation of biomass made from paddy straw was studied, then the generation cost of Ref-1, Plan-5, Plan-6, and Plan-7 with normalized PLF and variable cost.

4. Proposed Cofiring Technologies and Its Cost Estimation

4.1. Proposed method and technology for biomass cofiring at GHTP

(1) Mixing plan by introduction of biomass solid fuel conversion device

Biomass rice crops have "rice husks" in the spikes and “paddy straw" in the leaf stems. By introduction of grind mills, we have established the biomass solid fuel conversion. The grind mill can process the bale into molded product or powder as shown in Figure 4-1.

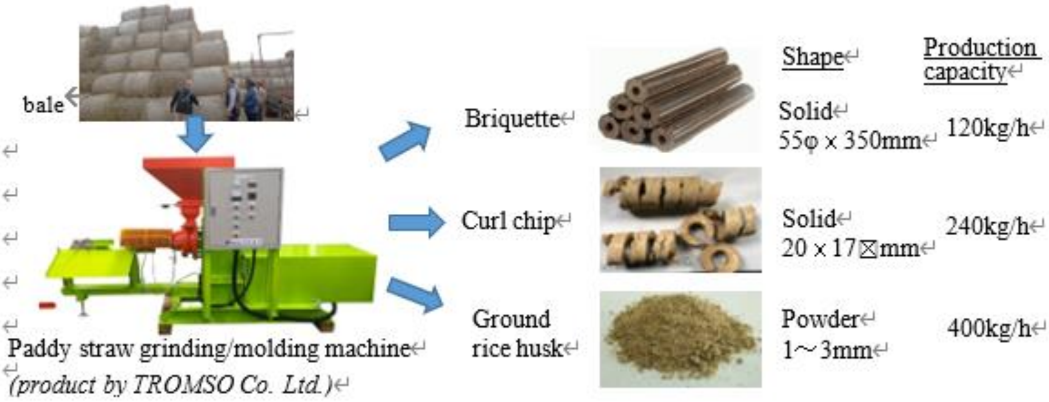


Figure 4-1 Biomass solid fuel conversion device and grinding production

The grind mill is a device that grinds rice husks and paddy straws through compression molding and heating processes. Grinding and solidifying can be done continuous by one unit. It is not necessary to add any adhesive. Paddy straws as well as rice husks contains much silica, therefore, they are very solid. The main parts of the grind mill are given a special surface treatment to greatly improve wear resistance.

(2) Selection of suitable molding process

We compared the production costs for type of “Briquette” and “Curl chip”. The type “Ground rice husk” was excluded because it is difficult to powder the fiber of paddy straw.

Firstly we tried the 50:50 mixing of paddy straw and rice husks, since in Japan paddy straw is normally used for plowing for fertilizer application and rice husks is used for embedded material for underdrain and the grind mill developed by TROMSO CO.,LTD. is prospective machine for producing the pellet, such as briquette or curl chip for cofiring fuel of coal fired boiler.

Estimated production cost of Briquette and Curl chip can be calculated by using the following calculation basis obtained through hearing during the survey.

- ✓ Paddy straw procurement cost: Rs 1,500 / t
- ✓ Rice husk Procurement cost: Rs 5,000 / t
- ✓ Electricity charges: Rs 5.9 / kWh

For utilization of paddy straw, firstly pretreatment to cut 1 m long paddy straw into about 13 mm with a chipper is required. Pretreatment cost is obtained as follows.

Table 4-1 Estimated paddy straw Pretreatment cost

	Item	Q'ty	Unit	Remarks
①	Paddy straw chipper (price)	17	10^4 Rs	Model: Cowa Cutter S200-E
②	Cutting capacity	250	Kg/h	Cut to 13 mm length
③	Annual processing time	480	h	8h/day x 20 days/mo. x 3mos./y
④	Annual cutting amount	120	Ton	② x ③ = 120 ton
⑤	Depreciation	0.61	10^4 Rs	7-year depreciation (① ÷ 7x 3/12mos.)
⑥	Labor costs	4.9	10^4 Rs	16,300 Rs (25,000 Yen)/mo. x 3mos.
⑦	Fuel cost	4.4	10^4 Rs	91 Rs (140Yen)/kg(ℓ) x ③
⑧	Consumables (for 3mos.)	0.2	10^4 Rs	650 Rs (1000Yen)/mo. x 3mos.
⑨	Pretreatment (cutting) cost	10.2	10^4 Rs	⑤ + ⑥ + ⑦ + ⑧
⑩	Pretreatment cost of 1kg	**0.85**	**Rs/kg**	⑨/④ = 0.085 x 10^4 Rs/t

1) Estimated Briquette production cost

It is assumed that 172.8 ton briquettes (paddy straw: rice husks = 50:50) are produced, that is, 86.4 tons each of paddy straw and rice husk, operating 8 hours a day and 20 days a month.

Table 4-2 Estimated Briquette production cost (paddy straw: rice husks = 50:50)

	Item	Q'ty	Unit	Remarks
①	Paddy straw procurement cost	13.0	10^4 Rs	1,500 Rs (2,300Yen)/t x 86.4t
②	Paddy straw pretreatment cost	7.3	10^4 Rs	0.85 Rs * (1.3 Yen)/kg x 86.4t
③	Rice husk procurement cost	43.2	10^4 Rs	5,000 Rs (7,690Yen) x 86.4t
④	Grind Mill Price	202	10^4 Rs	Mill purchase cost (incl. transportation)
⑤	Briquette production capacity	180	Kg/h	Equivalent to 100% rice husk treatment
⑥	Annual processing time	960	H	8h/day x 20 days/mo. x 6mos./y
⑦	Briquette annual production	172.8	Ton	⑤ x ⑥ = 172,800kg
⑧	Depreciation	14	10^4 Rs	7-year depreciation (④ ÷ 7x 6 /12mos.)
⑨	Labor costs	10	10^4 Rs	16,300 Rs (25,000 Yen)/mo. x 6mos./y
⑩	Electricity consumption	22,080	kWh	23 kW/h (mill power consumption) x ⑥
⑪	Electricity cost	13	10^4 Rs	5.9 Rs (9.1Yen) / kWh x ⑩
⑫	Consumables	40	10^4 Rs	414 Rs (636 Yen)/h x ⑥
⑬	Briquette production cost	140.1	10^4 Rs	① + ② + ③ + ⑧ + ⑨ + ⑪ + ⑫
⑭	Briquette production cost of 1kg	**8.2**	**Rs/kg**	⑬/⑦ = 0.81 x 10^4 Rs/t

2) Estimated Curl chip production coat

Assumed that 220.8 ton curl chips (paddy straw: rice husks = 50:50) are produced, that is, 110.4tons each of paddy straw and rice husk, operating 8 hours a day and 20 days a month.

Table 4-3 Estimated Curl chip production cost (2/2): Total production cost (paddy straw: rice husks = 50:50)

Item	Q'ty	Unit	Remarks
① Paddy straw procurement cost	16.6	10^4 Rs	1,500 Rs (2,300 Yen)/t x 110.4t
② Paddy straw pretreatment cost	9.4	10^4 Rs	0.85 Rs＊(1.3 Yen)/kg x 110.4t
③ Rice husk procurement cost	55.2	10^4 Rs	5,000 Rs (7,690Yen)x 110.4t
④ Grind Mill Price	156	10^4 Rs	Mill purchase cost (incl. transportation)
⑤ Curl Chip production capacity	230	Kg/h	Equivalent to 100% rice husk treatment
⑥ Annual processing time	960	h	8h/day x 20 days/mo. x 6mos./y
⑦ Curl Chip annual production	220.8	Ton	⑤ x ⑥ = 172,800kg
⑧ Depreciation	11	10^4 Rs	7-year depreciation (①÷7x 6/12mos.)
⑨ Labor costs	10	10^4 Rs	16,300Rs (25,000 Yen)/mo. x 6mos./y
⑩ Electricity consumption	17,760	kWh	18.5kW/h (mill power consumption)x ⑥
⑪ Electricity cost	10.5	10^4 Rs	5.9 Rs (9.1Yen) / kWh x ⑩
⑫ Consumables	24.5	10^4 Rs	255Rs (392 Yen)/h x ⑥
⑬ Curl Chip production cost	137.0	10^4 Rs	①+②+③+⑧+⑨+⑪+⑫
⑭ Curl Chip production cost of 1kg	**6.2**	**Rs/kg**	⑬/⑦ = 0.62 x 10^4 Rs/t

3) Suitable molding process

The manufacturing cost of 1 kg is 8.2 Rs/kg for briquettes and 6.2 Rs/kg for curl chips, therefore, most suitable molding process was confirmed to be Curl chip. The calorie of 1kg Curl chip is estimated to be about 4,000kcal (high calorific value).

On the other hand, according to GHTP, the power generation cost is 5,233 Rs. (8,043 yen) / ton (including transportation costs). Since the calorific value of coal used by GHTP is 3,982 kcal (high calorific value), the unit cost per calorie is lower than that of curl chip (see in Table 4-4). It is necessary to increase the cofiring ratio of cheap "Paddy straw", which is abundantly harvested in Punjab.

Table 4-4 Comparison of unit cost per calorific value by fuel (paddy straw: rice husks = 50:50)

Item	Production cost (Rs/kg)	Calorific value (kcal/kg)	Cost per calorific value (Rs/1000kcal)
Briquette	8.2	4,000	2.04
Carl Chip	6.2	4,000	1.55
GHTP Coal	5.23 *Table 1.1-6	3,982	1.31

Curl chips are better than briquettes, but still coals are lower than them.

4) Increase in paddy straw mixing ratio up to 90%: Estimated production cost

Assumed that 220.8 ton curl chips (paddy straw: rice husks = 90:10) are produced, that is, paddy straw 198.7 tons and rice husk 22.1 tons, operating 8 hours a day and 20 days a month.

Table 4-5 Estimated Curl chip production cost (paddy straw: rice husks = 90:10)

Item	Q'ty	Unit	Remarks
① Paddy straw procurement cost	29.8	10^4 Rs	1,500 Rs (2,300 Yen)/t x 198.7t
② Paddy straw pretreatment cost	17.0	10^4 Rs	0.85 Rs＊(1.3 Yen)/kg x 198.7t
③ Rice husk procurement cost	11.1	10^4 Rs	5,000Rs (7,690Yen)x 22.1t
④ Grind Mill Price	156	10^4 Rs	Mill purchase cost (incl. transportation)
⑤ Curl Chip production capacity	230	Kg/h	Equivalent to 100% rice husk treatment
⑥ Annual processing time	960	H	8h/day x 20 days/mo. x 6mos./y
⑦ Curl Chip annual production	220.8	Ton	⑤ x ⑥=220,800kg
⑧ Depreciation	11	10^4 Rs	7-year depreciation (①÷7x 6/12mos.)
⑨ Labor costs	10	10^4 Rs	16,300Rs (25,000 Yen)/mo. x 6mos./y
⑩ Electricity consumption	17,760	kWh	18.5kW/h (mill power consumption)x ⑥
⑪ Electricity cost	10.5	10^4 Rs	5.9 Rs (9.1Yen) / kWh x ⑩
⑫ Consumables	24.5	10^4 Rs	255 Rs (392 Yen)/h x ⑥
⑬ Curl Chip production cost	113.5	10^4 Rs	①+②+③+⑧+⑨+⑪+⑫
⑭ Curl Chip production cost of 1kg	**5.14**	**Rs/kg**	⑬/⑦=0.51 x 10^4 Rs/t

The cost evaluation by Tromso Co. Ltd. revealed that increase in paddy straw mixing ratio up to 90% from 50% can obtain the slightly better unit cost than coal.

Table 4-6 Comparison of unit cost by fuel (paddy straw: rice husks = 90:10)

Item	Production cost (Rs/kg)	Calorific value (kcal/kg)	Cost per calorific value (Rs/1,000kcal)
Curl chip	5.14	4,000	1.26
GHTP Coal	5.23	3,982	1.31

The following points will help us with impending development.

- ✓ Production costs can be reduced by expanding production scale
- ✓ By making the crushed size of paddy straw smaller than the current size (13 mm), we can maximize the mixing ratio of paddy straw, which is cheaper than rice husks, up to 100%, therefore, operation cost will be reduced.

The Table 4-7 shows the estimated manufacturing cost of curl chips with 100% paddy straw.

Table 4-7 Estimated Curl chip production cost (Curl chip with 100% paddy straw)

	Item	Qty	Unit	Remarks
①	Paddy straw procurement cost	3.30	lac	1,500Rs x 220.8ton
②	Paddy straw pre-treatment cost	1.87	lac	1.3Rs/kg x 220.8ton
③	Depreciation+labor costs+electricity charges+consumables costs	5.58	lac	
④	**Production cost of curl chip**	**4.87**	**Rs/kg**	(①+②+③)/220.8*10^5 Rs/ton

Comparison of unit cost per calorific value of Curl chip with 100% paddy straw and Coal are shown in Table 4-8.

Table 4-8 Comparison of unit cost by fuel (Curl chip with 100% paddy straw and Coal)

Item	Production cost (Rs/kg)	Calorific value (kcal/kg)	Cost per calorific value (Rs/1,000kcal)
Curl chip	4.87	4,000	1.22
GHTP Coal	5.23	3,982	1.31

Comparison of unit cost per calorific value shows that the unit cost of curl chips is even better than coal, which enhances the effect of biomass cofiring. To reduce the crushing size of paddy straw, we focus on improving capabilities including the selection of crushers so that the minimum cutting size can be reduced to the size of rice husks.

4.2. Result of Viability study on cofiring of agriculture waste

Based on our field survey and interview, we have reviewed the Proposed Remodeling Plans and obtained their generation costs and required tasks for each plan as shown in Table 4-9. Its cofiring ratio is 30 cal.% biomass. Power generation costs of existing units 5.9 Rs/kWh were informed from GHTP as current operating performance.

Table 4-9 Generation cost and required task for GHTP Cofiring after review

(Plan-7: Curl chip made from 100% paddy straw)

No.	Plan	Content	Fuel cost (Rs/kWh)	Capital investment (Cr Rs)	Power generation cost (Rs/kWh)	Task
Ref-1	Existing (In service)	GHTP 250MW (Existing)	3.5	-	5.9 (Heared value From GHTP) →5.54 (Corrected by load factor)	In operation but expensive
Plan-5	Biomass mixing system introduced	GHTP 250MW×1 (Remodeling)	2.66 →3.25	870	3.78 →5.97	Boiler modification required Pellet supply required
Plan-6	Fluidized bed boiler introduced	GHTP 250MW×1 (New unit)	2.73 →3.33	2170	5.30 →6.84	New boiler construction required
Plan-7	Pelletizer introduction + existing unit	GHTP 250MW×1 (Existing)	2.66 →3.25	110	2.96 →5.54	Biomass solid Fuel conversion equipm't required.

Those in the lower row (→) show the estimated value based on the results of the Secondary follow-up survey with normalized PLF and variable cost, where 20-year depreciation for Plan-5 and 6, and 7-year depreciation for Plan-7 were incorporated.

Plan-7 Pelletization using Curl chip is much profitable compared with other plans and comparable with the present plant operation.

4.3. Issues to be addressed for cofiring at existing coal fired PC boiler

(1) Issues in supplying biomass solid fuel with 100% paddy straw

- ✓ As mentioned in clause 4.1. (2) 4), one of issues to be addressed is to reduce the crushed size of paddy straw to obtain 100% paddy straw by "Curl chips", by biomass solid fuel conversion equipment. Currently, we can confirm up to 90%. We are planning to obtain 100% paddy straw by pretreatment of fine cutting (approximately 2-3 mm).
- ✓ Biomass supply: Understanding the upper limit from the surrounding supply.
- ✓ Scale-up of rice straw solidification equipment

(2) Issue to be addressed for Biomass cofiring

We have also studied the associated issue to be addressed for cofiring of agricultural waste for GHTP. Figure 4-2 shows the Issue to be addressed for Biomass cofiring.

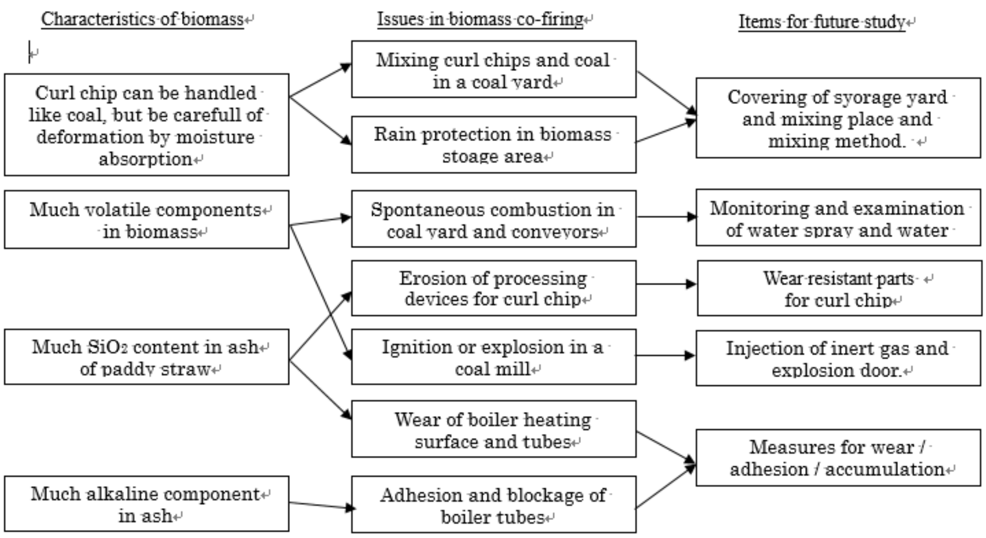


Figure 4-2 Issue to be addressed for Biomass cofiring

Figure 4-3 shows the points to be studied for stable boiler operation for biomass cofiring and Figure 4-4 shows the area to be studied for implementation of the curl chip collection, storing and mixing with the coal for conveying to the boilers.

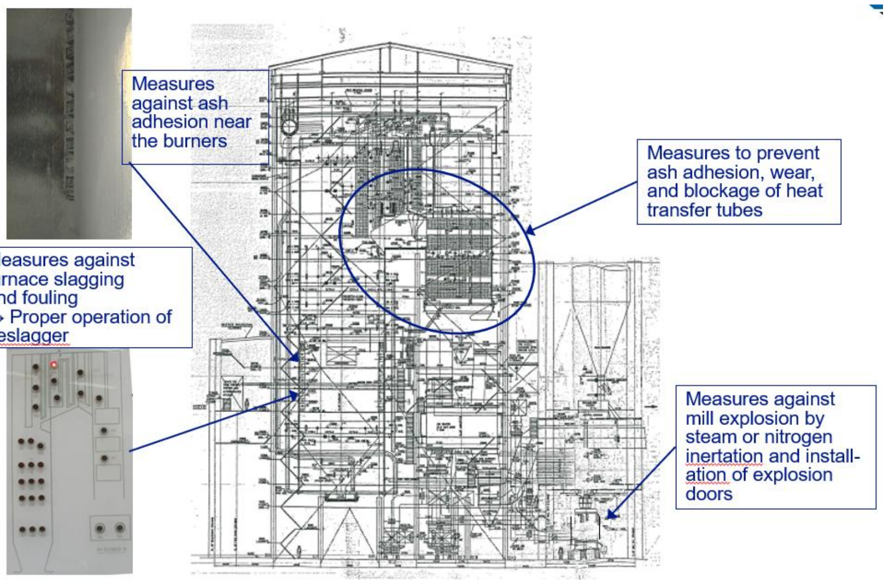


Figure 4-3 Issue to be addressed for boiler portion

- Biomass storage at the coal yard.
  - ✓ Secure the indoor curl chips storage space and new curl chip transfer conveyor and mixing facility for input to the existing coal conveyor will be installed.
  - ✓ Installation of a measurement scale for amount of curl chip mixture considering the installation of an appropriate mixer for coal and curl chip.
- Coal conveyor and bunker.
  - ✓ Maintaining proper mixing and safety for curl chips in coal bunkers.
  - ✓ Study of measures against powdering and scattering on conveyors.

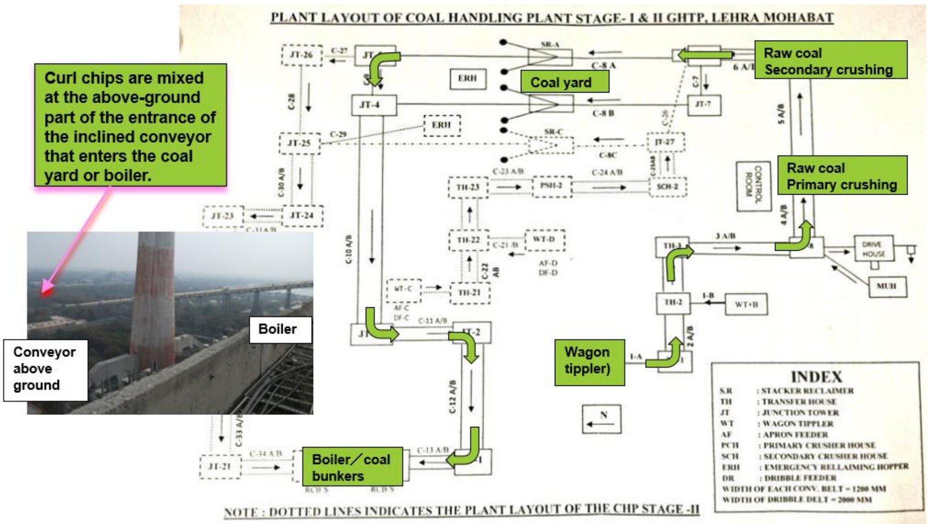


Figure 4-4 Issue to be addressed for Biomass storage at the coal yard

(3) Consideration on characteristic of paddy straw

The silica content in ash for paddy straw cofiring is assumed to be decreased as blue line shown in Figure 4-5. However, the effect of alkaline-rich ash deposit could affect the boiler heating surfaces. Ash influences on boiler inside such as slagging will be carefully considered.

Table 4-10 Elemental analysis of paddy straw and coal

Item	Wt.%	Paddy Straw	Coal
Ash	in fuel	11.0	39.0
Si	In ash	77.1	62.0
K	〃	14.4	1.9
S	〃	3.8	0.2
Ca	〃	3.6	1.7
Fe	〃	1.0	5.6
Al	〃	0	25.3
Mg	〃	0	1.1
Na	〃	0	0.4
Ti	〃	0	1.4
P	〃	0	0.4

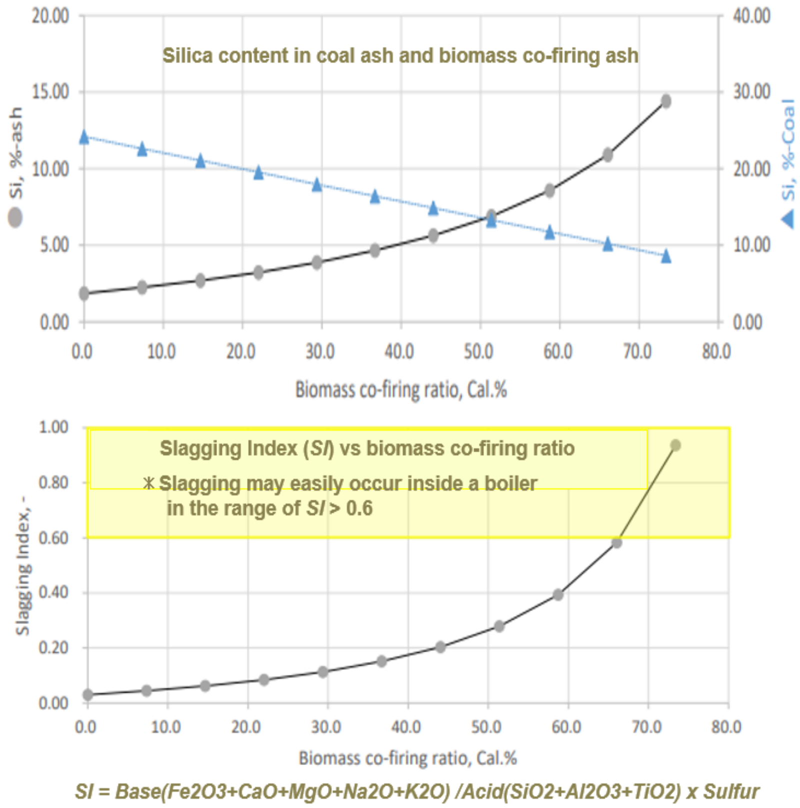


Figure 4-5 Effect of silica content in ash for paddy straw cofiring

5. Conclusion

Viability study on co-firing technology of agricultural waste and coal for air pollution control in India has been conducted in FY 2018 and 2019 at GNDTP and GHTP in PSPCL. Through the site survey, the plan of Installation of pelletizer without any modification of current facilities is estimated to be most feasible for cofiring at GHTP. Its conclusion is summarized in Table 5-1.

Paddy straw is a main biomass source which can be supplied from surrounding area.

Other influence of alkaline-rich ash deposit on boiler inside such as slagging will be carefully considered.

Table 5-1 Estimation of generation cost of cofiring at GHTP

	Plan	Content	Fuel cost (Rs / kWh)	Biomass ratio (cal.%)	Capital cost (Cr Rs)	Generation cost (Rs / kWh)
Reference	Current	GHTP 250 MW	3.50	-	-	5.54
Proposal	Pelletizer	GHTP 250 MW	3.25	30	110	5.54

Depreciation of pelletizer: 7 years

6. Way forward

The materialization of agricultural waste utilization an urgent issue in India not only protect air quality but also a practical measure of GHG mitigation. Demonstration project might be a better way prior to the installation of a commercial plant. Both sides have to consider an appropriate budget to conduct this demonstration.

Biomass mixing system and CFB boiler are also considered to be effective options for using biomass other than existing cofiring, for example, if there is a need for replacement, so, we will discuss the possibility with the Indian side in addition.

The study team will be happy that this report will be submitted to MOP by CEA for further consideration of biomass utilisation policy in India power sector to mitigate GHG.

Acknowledgments

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The study team also express an acknowledgement to NEDO for providing study budget.

Annexure

Information of biomass suppliers

Farm2Energy Pvt. Ltd.

Company	Farm2Energy Pvt. Ltd.
Business	Bailing of rice straw, wheat, maize and sugarcane
No. of bailer	Large-scale: 1 (100 acre/day) Medium-scale: 12 (30 acre/day)
Supply capacity	50,000t/year
Price of bales	Rs 1,800/t (excluding transportation cost)
Transportation cost	Rs 500/t for 100km Rs. 100-150/t for 10-20km
Customers	Power plant (25MW) : 1 (sugarcane factory) Factory : 2 (used as boiler fuel – not electricity generation)
Note	The largest independent collector of rice straws in Punjab State
Comments	✓ The nearest collection center is 10-20km away from GHTP. ✓ Though we are interested in supplying biomass fuels to GHTP, we can't invest further unless the standard of the fuel is set. ✓ We have a plan to build a CNG (CBG) plant and a bio coal plant utilizing the government's subsidy (Rs 40 million out of Rs 180 million investment)

ZAMINDARA

Company	Zamindara Farmsolutions Pvt. Ltd.
Business	Dealer of Swaraj tractors and bailers Aggregation of bales (get commissions from end users)
No. of bailers	Small-scale: 400 (owned and operated by contract collectors)
Supply capacity	800,000t/year
Price of bales	Rs 1,500/t (including transportation cost within 20km)
Transportation cost	Rs 500/t for 20km
Customers	Power plant (8-18MW) : 7-8
Note	The largest dealer of rice straw bales in Punjab State
Comments	✓ The nearest collection center is 30km away from GHTP. ✓ There might be much more cotton stalks rather than rice straws nearby GHTP. ✓ To ensure year-round supply of rice straws, customers (power plants) establish their own collection center and stock bales.