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Sustainable Life Cycle Analysis (LCA) approach and Reduction of Potential Slagging, Fouling and Corrosion Problems in Boilers of Power Generation Systems at Coal-Fired Power Plants

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Abstract: ***The utilization of biomass in Coal Steam Power Plants (PLTU) in the form of biomass co-firing is targeted to reach new and renewable energy (NRE) of around 23% by 2025, therefore co-firing is needed by approaching a portion of 10-20% or requires biomass of around 8 million tons-14 million tons per year. The main factors that affect heat transfer in boilers can occur due to the low melting point of biomass and the relatively high alkali content so that it becomes a problem of slagging, fouling and corrosion. One of the ways used to overcome this is by adding additives to the fuel mixture through biomass co-firing methods and a sustainable LCA approach. Life Cycle Assessment (LCA) is an approach used to calculate the economic, social and environmental impact on a product, so in the selection of biomass co-firing fuel using materials that can cause better emissions. The scope of LCA calculation is on the preparation of raw materials (gate to gate), which includes fuel preparation activities from the land, seeding, planting, fertilizing, maintaining and permanence biomass fuel. Then it is planned until implementation in the industry (cradle to gate), in accordance with the roadmap of the future program that is more structured and advanced.***

Keywords: biomass co-firing fuel, supply chain, biomass co-firing fuel, Coal Steam Power Plants, slagging, fouling and corrosion, Life Cycle Assessment

1. Introduction

Supply chain is a relationship between many parties, from the supply of raw materials, production processes, distribution, use of products to consumable products, both directly and indirectly involved.

A supply chain will be superior to others supported by the ability of the supply chain to adapt to technological and customer changes. One of the efforts that can be made to achieve Net Zero Emissions by 2060, namely by implementing a strategy to accelerate the use of new and renewable energy through energy substitution from biomass.

The realization of the strategy is realized through the biomass co-firing program at the existing coal-fired power plant. This program uses biomass both based on waste, waste and biomass derived from plants. This co-firing has been implemented in other countries that have realized more "green" coal-fired power plants.

Co-firing is the process of adding biomass as a partial replacement fuel to a coal boiler without making significant modifications. Regulatory support for the acceleration of the implementation of the biomass co-firing program at coal-fired power plants in Indonesia has been formulated.

The strategic role of co-firing pltu biomass includes reducing greenhouse gas (GHG) emissions, increasing the NRE mix, easy and cheap without the need to build new plants because it utilizes existing coal-fired power plants, reducing fossil energy and waste management, as well as achieving community welfare because it is a multiplier effect for community welfare. for the welfare of the community in the provision of Biomass through the involvement of community participation in the provision of Biomass and land preservation programs, so as to simultaneously increase the economic growth of the local community.

The biomass co-firing program synergizes with campuses, communities, social institutions, State-Owned Enterprises and the community as part of supporting the implementation of clean energy in the context of the energy transition (PLN, 2022). The supply chain in the implementation of co-firing of Biomass fuel power plants in Indonesia includes PT PLN, non-PLN wilus (business area) holders, Temporary Electricity Supply Business License holders (IUPTLS) and providers / suppliers of Biomass materials

The coal-fired power plant co-firing program with Biomass is one of the PLN "Green Booster" programs to support the national NRE energy mix target. PT. Java Bali Power Plant (PT. PJB) became a pioneer in pltu co-firing activities in Indonesia. This pioneering was marked by the implementation of Go Live Co-Firing Biomass on June 10, 2020 at the Paiton generating unit

This success is the fruit of a series of studies conducted by PJB related to co-firing since 2019. PT. PLN has conducted co-firing tests on a number of coal-fired power plants owned by the Main Unit and Subsidiaries, of which 32 plants have entered the commercial implementation stage. PT PLN has issued a Regulation of the Board of Directors of PLN related to Guidelines for the Implementation of co-firing coal-fired power plants with Biomass fuel August 2022, regulations from the Ministry of Energy and Mineral Resources on the use of Biomass as a fuel mixture in coal-fired power plants on the status of redrafting and finalization of the Draft Regulation of the Minister of Energy and Mineral Resources. Related to reducing the use of coal, initiatives have been developed using Biomass through collaboration between BUMN.

Collaboration between PT PLN and Perhutani through the provision of sawdust supply to pltu Pelabuhan Ratu amounting to 11.5 thousand tons per year and PLTU Rembang amounting to 14.3 thousand tons per year. In addition, the use of rice husk pellets for co-firing in collaboration between PT PLN and PT Sang Hyang Seri

Collaboration between PT PLN and PT Perkebunan Nusantara on the use of empty bunch husk pellets for co-firing. An evaluation of the environmental impact and benefits of biochar co-firing supply chains for generation has been carried out by Huang et al (2012). Biochar is assumed to be produced by rice straw torrefaction. Case study conducted in Taoyuan County, Taiwan

Supply chains can provide impact reduction benefits in 5 (five) categories, namely aquatic ecotoxicity, terrestrial ecotoxicity, land, global warming and non-renewable energy. However, other impact categories show a higher impact compared to the coal burning system.

Model Life Cycle Assessment (LCA)

According to ISO 14040 in the World Business Council for Sustainable Development (2002), the definition of LCA is a technique developed to understand and deal with the impact of products when they are produced and when consumed. This LCA consists of 4 main phases which can be seen in Figure 1.

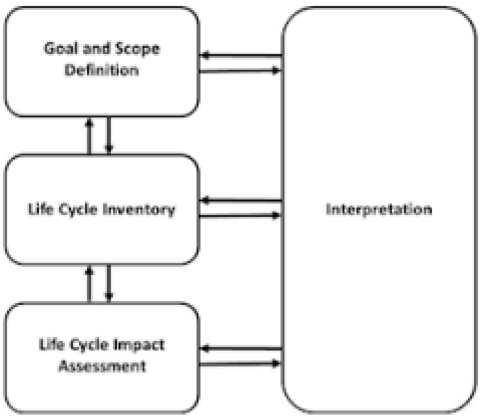

Figure 1: Fase Life Cycle Assessment (LCA)

a) Goal and Scope

Formulate and describe the objectives, the system to be evaluated, the limitations and assumptions related to the impact throughout the life cycle of the system.

b) Life Cycle Inventory (LCI)

Shows the environmental influence per-part of the life cycle. This stage is a process of quantification of energy and material needs, air emissions, solid waste and all outputs discharged into the environment during the product life cycle.

c) Life Cycle Impact Assessment (LCIA)

Grouping and assessment of the effects caused to the environment based on the data obtained at the LCI stage.

1) Classification and characterization. Identify and group substances that contribute to the category of impact.
2) Normalization. The procedure required to show the relative contribution of the characterization value to the normal value.
3) Weighting. Weighting is obtained by multiplying the impact category by the weighting factor and adding to get the total value.
4) Single score. Used to classify impact category values by activity or process. The single score value will show which activities contribute to environmental impact.

d) Interpretation

Is an integration of life-cycle inventory and life cycle impact assessment used to review, draw conclusions and recommendations In accordance with the revision of the Minister of LH Regulation Number 3 of 2014 concerning PROPER, new criteria have been added, from which the application of Life Cycle Assessment (LCA) has been added. The application of this life cycle assessment (LCA) aims to identify, calculate the sustainability of the use of natural resources, disposal in the environment and evaluate and Life Cycle Assessment refers to the ISO 14040: 2006 standard which has been adopted into SNI ISO 14040: 2016 and ISO 14044: 2006 or has been adopted into SNI ISO 14044: 2017. apply possible environmental improvements.

Improving the efficiency of co-firing generation systems is important to do to reduce the impact of environmental damage. In Indonesia, there have been several studies related to LCA on the use of biomass, including research by Taufan et al (2012). The research conducted was an evaluation of the environmental impact of coal and biomass use at PT Holcim Indonesia.

The scope studied was cradle to gate, by evaluating 4 fuel usage scenarios:

1) 100% coal,
2) a mixture of 90% coal and 10% Biomass,
3) a mixture of 50% coal and 50% Biomass,
4) 100% Biomass, with a base of 1, 000 kg of cement products.

The results of the analysis show that the global warming, respiratory inorganic and resources impact categories are the largest contributors to the total impact on the environment. Analysis of improvements and recommendations to reduce the impact that occurs, namely replacing silica sand truck transportation with trains, Biomass fuel using miscanthus giganteus and greening.

Siregar et al (2020) have conducted an LCA analysis on the gasification integration system with gas engines, which work well with CO and H2. The scope studied is cradle to grave. The results showed that greenhouse gases (GHG) from the production of empty bunches of palm oil mills amounted to 0.15 kh CO2 eq kWh. Gas engines are the highest contributor to emissions during the life cycle. Empty bunches as a climate-friendly source of biomass, which has the potential to reduce GHG exhaust emissions.

LCA analysis on wood pellets made from Eucalyptus Pellita plantations, at 1 planting cycle (6 years) showed that GHG emissions generated from plantation activities were mainly from diesel-based energy consumption of 678.0270 kg CO eq. Meanwhile, wood pellet mills only release GHG emissions of 0.1053 kg CO eq.

Thus, the total emission of wood pellets for 6 years is much lower than the average CO absorbed by plantation forests (Iswanto, 2021).

LCA on biodiesel production in Indonesia from the plantation phase through the production phase produces a greater effect. The results of the analysis show that the main contributor to the environmental impact of biodiesel production is fertilizer consumption during the planting stage and the transesterification process at the diesel plant (Paminto, Karuniasa and Frimawaty, 2022).

In addition, an analysis has been carried out on the use of empty palm oil bunches waste as co-firing at coal-fired power plants by Praevia and Widayat (2022). Empty bunches of oil palm can be used as co-firing at existing coal-fired power plants using the direct co-firing method. Empty bunches of palm oil are mixed with coal before entering the boiler unit. To reduce the impact of ash from burning biomass, such as alkaline content, high water content, Low calorific value is recommended the process of improving fuel quality by means of Hydrothermal Treatment (HT).

The result of heating is obtained char (carbonated biomass) with the same quality as coal. Research shows that by undergoing a carbonation process with hydrothermal treatment, an increase in the calorific value of empty bunches were obtained from 7.86 MJ / kg to 22.22 MJ / kg (compared to coal 22.34 MJ / kg).

Objectives and Objectives The objectives of this research are

1) Assessing the biomass fuel supply chain as a co-firing of coal-fired power plants in order to be sustainable.
2) Life Cycle Assessment for co-firing coal-fired power plants.
3) Assessing the economic, social and environmental impacts of using Biomass fuel.
4) Assessing the effectiveness of Biomass fuel as co-firing of coal-fired power plants in Indonesia.

The target of this research is the production of recommendations for Biomass standards and biomass fuel supply chain patterns as well as the assessment of their life cycle as co-firing coal-fired power plants.

The formulation of the problem in this research is:
1) How the biomass fuel supply chain that can be used as co-firing of coal-fired power plants in Indonesia, in terms of actors and estimates of the sustainability of raw material supply.
2) How to select effective and environmentally friendly Biomass fuel using the Life Cycle Assessment method.
3) What kind of raw material is best for Biomass fuel as a co-firing of coal-fired power plants in Indonesia, which is sustainable.

This research was conducted by conducting literature studies, field surveys, and questionnaires using quantitative and qualitative analysis research methods to determine the supply chain of Biomass fuel for co-firing coal-fired power plants. Quantitative analysis using the LCA method, to calculate environmental impact using Open LCA software.

Identify the sustainability of the biomass fuel supply chain that will be carried out on the co-firing of the power plant. Then conduct the selection of Biomass fuel to be used with the Life Cycle Assessment (LCA) method which has a low environmental impact. LCA is an approach used to calculate economic, social and environmental impacts with a cradle to grave bounderies system that covers the entire product life cycle. The phases of the LCA are goal and scope, life cycle inventory, life cycle impact assessment, and life cycle interpretation.

Life cycle assessment framework Description of the life cycle assessment framework:

1) Goal and scope definition is a clue that can help consistency of LCA research. The purpose should indicate the reason for conducting the study and what the research is for. The scope of the explanation of the research methods used, assumptions, and limitations.
2) Input stage of inventory analysis (life cycle inventory) Inventory inputs and outputs related to the scope of the study. The purpose of this analysis is to show the environmental influence per part of the life cycle.
3) Life cycle impact assessment Evaluation of potential impacts on the environment using the results of life cycle
4) Life cycle interpretation stage the final stage of life cycle analysis provides conclusions, recommendations, and decision making. inventory and providing information to interpret in the last phase

2. Result and Discussion

Steam Power Plant is a power plant that uses steam to drive turbines and generators. Steam is produced from steam generators or often referred to as boilers which generally use coal fuel as a producer of heat energy to convert water into steam.

Co-firing using biomass is currently booming in all PLN generation lines, especially in coal-fired power plants in order to increase the energy mix that utilizes new and renewable energy (NRE) from previously using coal (fossil) fuels to the use of biomass fuels to reduce coal consumption.

Co-firing is the combustion of two or more types of fuel simultaneously for a given process. For example, coal-fired power plants that have conducted co-firing trials are the Anggrek power plant with a mixture of 95% coal fuel and 5% Lamtoro woodchip.

The following thread we will share how to analyze the level of slagging and fouling rate in a fuel based on the results of proximate analysis and the ultimate analysis of the Certificate of Analysis (COA) of a solid fuel. The phenomenon can be influenced by ash fushion temperature and the elements contained in the ash.

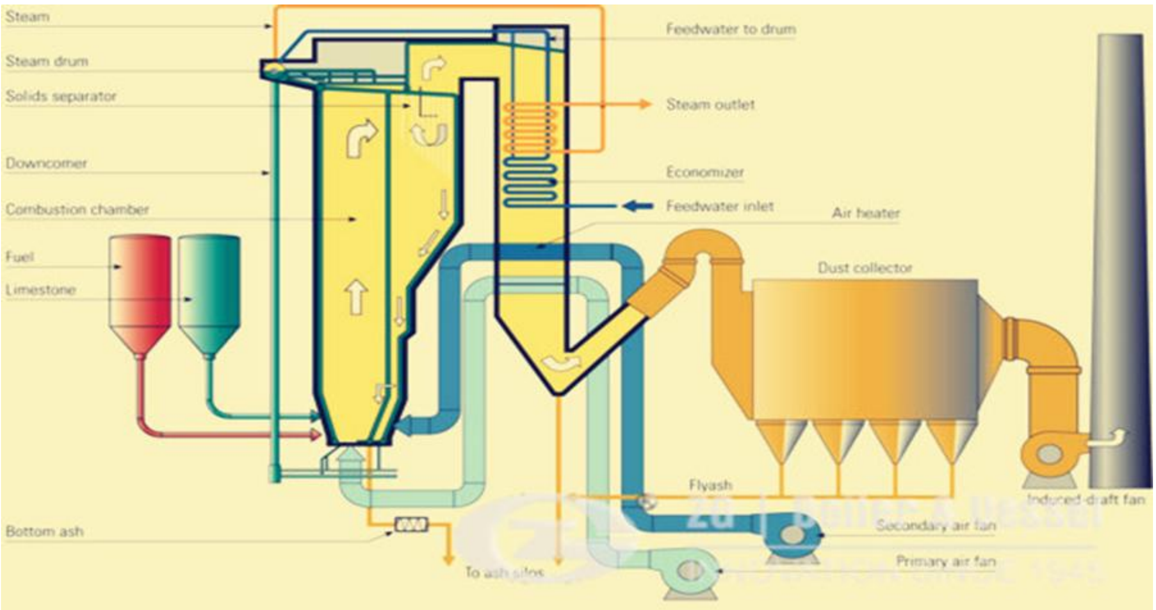

Figure 2: Circulating fluidized bed boiler (for example)

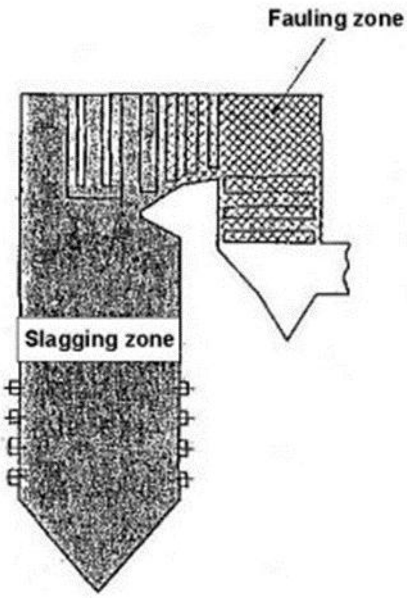

Figure 3: Zone of slagging and fauling

The figure above shows the zone of occurrence of slagging and fouling in the combustion chamber, where the slagging zone in the area of combustion occurrence with high temperature conditions, while the fouling zone occurs in the area of advanced heat utilization (Heat Recovery Area).

Slagging is the phenomenon of sticking ash particles of both solid and melting form, on the surface of the heat-conducting wall located in the high temperature zone. As we know that, agglomerations formed in the combustion zone (furnace) will be able to interfere with the air flow rate process for fuel fluidization and bed material at the CFB PLTU furnace.

The agglomeration is formed from the slagging process in the furnace due to temperatures that exceed the ash softening temperature. Meanwhile, the agglomeration of the material clumping process in the combustion chamber occurs due to the same phenomenon as the slagging phenomenon.

The phenomenon of slagging or agglomeration that occurs in furnaces is often not detected even though temperature parameters have been set in the furnace so as not to exceed the melting temperature of coal ash and bed material (generally kept smaller than 950 °C). This happens because there are high temperature spots in the combustion process in the furnace which is not a sensor point for the furnace temperature reader.

The process of slagging / agglomeration occurs starting from the fuel ash / bed material in the furnace that reaches an area of the furnace and exceeds the point of softening the ash then moves and attaches to the boiler tube or with other ash in areas that have a lower temperature (as a result of the bubbling process). Because the temperature is lower than the temperature of the ash softening, the ash that has been attached to the heat-conducting wall () or stick with ash or coal or bed material and then harden. This can be instability of the bubbling and combustion process in the furnace and has the potential to increase the high temperature spots that occur in the furnace and the increasing agglomeration.

Foiling is the phenomenon of ash sticking to the heat-conducting wall (in the superheater or reheater area). The element that has the most influence on the attachment of this ash is alkaline material, especially Na, which in this case is the level of Na2O. If the coal ash content is a lot, then the alkaline elements in the ash are also a lot, plus the high Na2O content, then fouling will easily occur.

The evaluation of slagging and fouling characteristics is the same, that is, it is judged based on the ratio of alkaline and acidic elements, as well as the level of Na2O in the ash. If these values are high, then in general the tendency to fouling also increases.

The initial steps to determine the slagging level and fouling rate of a fuel are to compare CaO coupled with MgO smaller than Fe2O3 considered bituminous type ash otherwise called lignite-type ash.

Abu tipe bituminus:

$$Rs\ (\text{Slagging Index}) = \frac{Fe_2O_3+CaO+MgO+Na_2O+K_2O}{SiO_2+Al_2O_3+TiO_2} \times S$$

$$Rf\ (\text{Fouling Index}) = \frac{Fe_2O_3+CaO+MgO+Na_2O+K_2O}{SiO_2+Al_2O_3+TiO_2} \times Na_2O$$

Abu tipe lignit:

$$Rs\ (\text{Slagging Index}) = \frac{HT(Hemisphere\ Temp)+4IDT\ (Inisial\ Deformation\ Temperature)}{5}$$

$$Rf\ (\text{Fouling Index}) = kadar\ Na_2O\ (\%)$$

Abu tipebituminus:
Standar slagging: Standar Fouling:

Potensi slagging	Rs
Low	0.6<
Medium	0.6 ~ 2.0
High	2.0 ~ 2.6
Severe	>2.6

Potensi fouling	Rf
Low	0.2<
Medium	0.2 ~ 0.5
High	0.5 ~ 1.0
Severe	>1.0

Abu tipelignit:
Standar slagging: Standar Fouling

Potensi slagging	Rs (^{0}C)
Low	>1340
Medium	1340 ~ 1230
High	1230 ~ 1150
Severe	1150<

Potensi fouling	Rf
Low	1.2<
Medium	1.2 ~ 3.0
High	3.0 ~ 6.0
Severe	>6.0

The slagging index of lamtoro wood material is very low due to the very high melting point temperature of the reduction ash. However, the fouling rate in lamtoro wood is high due to the high Na2O content in lamtoro ash. The characteristics of teak wood and palm shells are almost the same as coal, namely they have a high slagging tendency, but a low fouling rate.

Mixing coal /blending with lamtoro wood has the advantage of reducing the possibility of slagging and also the level of fouling as fuel in pltu boilers

LCA analysis on wood pellets made from Eucalyptus Pellita plantations, at 1 planting cycle (6 years) showed that GHG emissions generated from plantation activities were mainly from diesel-based energy consumption of 678.0270 kg CO eq. Meanwhile, wood pellet mills only release GHG emissions of 0.1053 kg CO eq

Thus, the total emission of wood pellets for 6 years is much lower than the average CO absorbed by plantation forests from the Director of Forest Business of the Ministry of Environment and Forestry, Mr. Iswanto, 2021.

LCA analysis on biodiesel production in Indonesia from the plantation phase through the production phase produces a greater effect. The results of the analysis show that the main contributor to the environmental impact of biodiesel production is fertilizer consumption during the planting stage and the transesterification process at the diesel plant in his article Comparison of Biofuel Development in Indonesia (Paminto, Karuniasa and Frimawaty, 2022).

Analysis of the utilization of empty palm oil bunches waste as co-firing at coal-fired power plants in his article Analysis of the Utilization of Empty Bunches of Palm Oil as Cofiring at coal-fired power plants by Praevia and Widayat (2022). Empty bunches of oil palm can be used as co-firing at existing coal-fired power plants using the direct co-firing method. Empty bunches of palm oil are mixed with coal before entering the boiler unit. To reduce the impact of ash from biomass combustion, Heating is obtained char (carbonated biomass) of the same quality as coal. Research shows that by undergoing a carbonation process with hydrothermal treatment, an increase in the calorific value of empty bunches were obtained from 7.86 MJ / kg to 22.22 MJ / kg (compared to coal 22.34 MJ / kg).

Other Methods

Slagging Analysis

$$\text{Rasio Alkali dalam Abu} = \frac{unsur\ \ alkali}{unsur\ \ asam}$$

$$= \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_2}$$

Potensi Slagging	Rasio basa/ asam
Low	0.4<
Medium	Atau > 0.7
High	0.4~0.7
Severe	

Alkaline Na2O + K2O
This alkaline element will form compounds with low melting points when bonded with other elements. An increase in the tendency for slagging will also be followed by an increase in the tendency for fouling, according to the alkali content in the ash. Boiler manufacturers usually specify a total alkaline value of less than 5%, with an ideal value of less than 3%. Na2O and K2O easily form compounds with low melting points which are often referred to as "total alkali metal oxides".

Iron/calcium comparison
The ratio between 0.2-10 will affect the decrease in the melting temperature of the ash, with the ratio 0.3-3 showing an interesting phenomenon. So, the tendency for slagging will increase in this value range.

Iron oxide levels
Calcium oxide (CaO) is added to iron oxide (Fe2O3) so that the melting temperature will decrease and the slagging tendency will increase. For this reason, the Fe2O3 level is expected to be no more than 15%. For boiler designs, generally has a maximum value of 20%. Besides that, high levels of iron oxide will also cause the ashes to have a reddish color

Na2O levels
Sodium is the element that most influences the occurrence of fouling. Fuel whose ash (regardless of the type of ash) contains Na2O with a content greater than 2% indicates a high fouling tendency. However, for power plants in Japan, the standard is below 0.1%, because sodium is easily bound by Electrostatic Precipitator (ESP).

Based on the Certificate of Analysis (COA), the data for the four types of fuel is then analyzed for slagging and foiling where the first step is to determine the type of ash by comparing the percentage of CaO + MgO with the percentage of Fe2O3. It was found that all of these fuels had lignite type ash, so the calculation of the slagging and fouling indices used the lignite type ash formula.

Parameters	Units	Batubara COA Shipment 26	Kayu Lamtoro	Kayu Jati	Cangkang Sawit
Analisa slagging & Fouling					
CaO+MgO		38.04	62.65	41.02	19.45
Fe2O3		21.96	2.78	0.93	10.87
Jenis Abu		Lignit	Lignit	Lignit	Lignit
Indeks Slagging		1215.8	>1500	1156.6	1166.8
Type Slagging		**High**	**Low**	**High**	**High**
Indeks Fouling		0.54	3.96	0.16	0.73
Type Fouling		**Low**	**High**	**Low**	**Low**

Figure 4: Examples of biomass from Lamtoro wood, teak wood and palm shells.

A reference for the Indonesian government to continue to strive to reduce the use of fossil fuels. Furthermore, there are several related studies that focus on identifying the ratio of biomass and coal before being burned at an existing coal-fired power plant.

Problems that may occur based on the exposure presented above are the supply chain of biomass fuel as co-firing of coal-fired power plants, LCA co-firing of coal-fired power plants as well as the economic, social and environmental impacts of the use of biomass fuel and the effectiveness of biomass fuel as co-firing of coal-fired power plants. The selection of biomass co-firing raw materials needs to be carried out a Life Cycle Assessment (LCA). So it is hoped that not only the achievement of solutions to slagging, fouling and corrosion problems in boilers can be resolved, the Biomass fuel used can also use materials that can cause lower emissions.

The alternative types of Biomass raw materials that LCA will calculate are based on the results of literature studies and field surveys conducted. In accordance with the program roadmap, the limit on the scope of LCA calculation in 2023 is on the preparation of raw materials (gate to gate), which includes land preparation, seeding, planting, fertilization, maintenance and fuel harvesting activities. Then planned for the following year, the LCA calculation is carried out at the raw material preparation stage, which includes land preparation activities, breeding, planting, fertilizing, caring and harvesting raw materials, to the implementation of prototypes in the industry (cradle to gate), in accordance with the roadmap of the next year's program, namely implementation assistance by the industry.

3. Conclusion

Various inputs have been made before with the input that generation with co-firing can provide considerable cost additions by including various inputs for biomass fuel substitutes. However, considering the ability of new and renewable energy with attention to the overall generation system, it is a part that needs to be addressed as soon as possible.

A comprehensive range of inputs is needed from all existing steam power generation by including well-structured cofiring that can provide sustainable economic circulation coupled with including environmental impact analysis as a prominent part and getting meaningful input for the potential for overall heat support to be developed so that the welfare of the people can become a prosperous nation and a state that is firm and just.

Improved levels of bituminous ash and lignite ash are options that can promote good progress and blessings with the chemical levels required of any steam power plant from coal fuel.

Acknowledgment

We as the reviewer of National Research and Innovation Agency would like to thank all leaders ranging from the Head of Center for sustainable production systems research and life cycle, and institutional leaders above it so that the writing and institutional leaders above it so that our writings can be completed properly so that their concentration can be implemented into all work units related to it and further preparations towards sustainable development for the progress of the Indonesian nation. Hopefully, our input about Development of waste cooking oil strengthens biodiesel-based derivative products can be a part desired by all employees who are professional and the best for the progress of the Indonesian nation of Success for the whole.

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