

# Potential and Opportunity of Co-Firing Power Plant in Indonesia Through Torrefaction of Empty Fruit Bunch (EFB) - A Review

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## ABSTRACT

Electricity was an important requirement for various activities. Currently the level of electricity consumption in Indonesia was around 1000 kWh/capita/year and expected to continue to increase towards developed countries with a minimum electricity consumption level of 3000 kWh/capita/year. Along with the increasing demand for electricity, many new power plants were being built in Indonesia using coal as fuel. Coal was a non-renewable fuel so the CO<sub>2</sub> gas produced has an impact on global warming. Co-Firing was a technology for combining fuel of biomass and coal in order to reduce the use of coal. The difference in the quality of biomass and coal was an obstacle to getting a stable combustion performance so it is necessary to improve the quality of biomass. The torrefaction technology can be implemented to improve the quality of biomass in Indonesia so it can be used as fuel for a co-firing power plant. One of the most potential biomass was empty fruit bunch (EFB) from palm oil processing with a potential of around 48 million tons per year or equivalent to 30 GW. Every Oil palm mills plant that process 25 ton/hour of fresh oil palm fruit bunches can produce EFB around 5.25 ton/hour. With so many palm oil plant, torrefaction technology can be used to store EFB torrefied which can change the properties of biomass from hydrophilic to hydrophobic. The government's role to support the use of biomass, including EFB, is very much needed in increasing cooperation between palm oil mills and power plants.

**Keywords:** biomass, power plant, co-firing, torrefaction, empty fruit bunch

## 1. INTRODUCTION

The need for electricity in Indonesia was increasing along with improving people's lives with estimating increase in electricity demand of 6.9% per year (Ali Akhmad Noor Hidayat, 2019). The driving factor for the increased demand for electricity was the increasing number of electrical home appliances such as electric stoves, rice cookers, refrigerators, air conditioners and so on. In the future, the government will plan to use electricity for vehicles and stoves in home appliance. Thus, electricity consumption will increase at present and in the future. Meanwhile, the level of electricity consumption in Indonesia was still low compared to the consumption level of several countries in ASEAN as shown in Table 1. In this table, Indonesia's electricity consumption rate in

2018 was still low around 972 kWh/year/capita. If Indonesia will to become advanced, the national electricity consumption must be above 3000 kWh/year/capita or three times of the condition in 2018. In 2020, the installed capacity of power plants in Indonesia was 70 GW. (Humas EBTKE, 2020) thus the installed electricity capacity requirement is estimated at 250 GW to achieve a national electricity consumption of 3000 kWh/year/capita with a population increase of 1.25 %/year in accordance with the results of the 2020 census.(BPS, 2021) .

The installed capacity of the power plant was 70 GW, the fuel used was dominated by coal 49.9%, natural gas 28.6 %, EBTKE 14.8 % and the rest from oil by 6.7 % (ESDM, 2020). The increase in the earth's temperature was due to the large amount of CO<sub>2</sub> gas produced from

combustion in industry, vehicles and households. The burning of coal in the power generation provided a major contribution to global warming. Several studies have been conducted to capture CO<sub>2</sub> produced using Carbon Capture and Storage technology to reduce the impact of global warming on coal use (Shukla et al., 2020)(Wilberforce et al., 2021)(Osman et al., 2020) (Pudasainee et al., 2020). In addition, burning coal produced SO<sub>x</sub>, NO<sub>x</sub> and particulate gases that impact on the human health and the environment (Zhang, 2019)(International Energy Agency (IEA), 2016). Several countries that mostly use coal as fuel in power plants had conducted research for clean coal technology (Speight, 2021). With this technology, it is expected that the impact of the use of coal on human health can be minimized. Research on clean coal technology continued to develop to utilize exhaust gas as a chemical so added value from the use of flue gas from combustion can be obtained (Nandy et al., 2016). However, technology to reduce the impact of coal use still required high investment in equipment systems so some coal power plants cannot implement CO<sub>2</sub> capture and storage technology as well as clean coal technology.

Table 1. Electric Consumption of ASEAN Countries, China and Japan in 2018 (IEA, 2018)

No	ASEAN Countries	Electric Consumption (kWh/Capita/year)
1	Singapore	8343
2	Brunei	8206
3	Japan	7150
4	China	4617
5	Malaysia	4608
6	Thailand	2669
7	Vietnam	2250
8	Indonesia	972
9	Philippines	863
10	Laos	566

Due to the high cost of clean coal technology, several other alternatives need to be made to reduce the impact of coal use on humans and the environment. One of the alternatives to reduce the environmental impact on existing power plant was co-firing technology (Al-Naiema et al., 2015) (Xu et al., 2020). Co-firing was a method of providing heat in power generation by combining fuel between coal and biomass (Fig. 1).

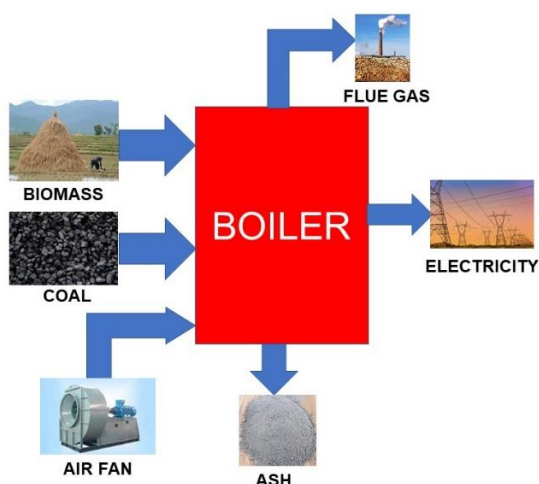


Fig 1. Schematic of Biomass Co-firing in Coal Power Plant

American and European countries have shifted power generation fuel from coal to biomass using co-firing technology (Al-Mansour & Zuwala, 2010) (Xu et al., 2020). This was in accordance with the Paris Agreement to reduce the use of carbon from fossil fuels which produce CO<sub>2</sub> gas emissions so global warming can be controlled (Clancy et al., 2018; Murphy & McDonnell, 2017).

Several American and European countries faced obstacles in the supply of biomass due to limited natural resources to be used as biomass (Agbor et al., 2014). Indonesia was abundant with biomass from various sources, like waste from forest products, agriculture, plantations and even municipal waste with a potential of around 50 GW. (Singh & Setiawan, 2013) (Mahidin; et al., 2019). Some of these biomass sources had been collected in one location, such as rice husks, waste from palm oil, municipal solid waste (MSW). Indonesia as an archipelago country means that the biomass source on an island can be optimized for local power plants and this condition reduces logistics costs. Rice husks and MSW are mostly located on Java because Java Island has the largest population in Indonesia. Then the plantation and forestry processing waste, many of which are outside the Java, such as Sumatra, Borneo, Celebes. Thus, biomass must be optimized for national energy security because the potential possessed by Indonesia was very abundant.

One of the major biomass in Indonesia was produced from palm oil processing. Indonesia has a very large oil palm plantation of around 14.6 million hectares with crude palm oil (CPO) production of 48.42 million tons in 2019 (BPS, 2020). Every ton of fresh fruit bunches (FFB) that was processed, can produce as much as 0.24 ton of CPO and 0.21 ton of empty fruit bunches (EFB). (Hambali & Rivai, 2017). With the production of 48.42 million ton of CPO in 2019 so 42 million ton of EFB can be produced per year. Until now, EFB was used as mulch in palm oil plantations because EFB contains nitrogen, phosphorus, potassium, magnesium and carbon components needed by oil palm plantation (Boafo et al., 2020). EFB can also produce ash from incineration but this condition causes emissions because the ash as a catalyst to accelerate the formation of NO<sub>x</sub> emissions. (Akhtar et al., 2018). In addition, EFB was also used for industrial composting and fiber production (Chiew & Shimada, 2013). Even though there have been several uses of EFB, there are still many EFB that have not been used so that EFB becomes waste. With such a large amount of potential, EFB can be used as fuel, including in power plants, by first improving its quality through pre-treatment.

Thus, co-firing technology has the opportunity to be implemented to power plants in the framework of utilizing EFB in Indonesia. This condition can reduce the use of coal in the power plant while reducing CO<sub>2</sub>. This paper aims to describe the potential and opportunities of oil palm empty bunches in Indonesia as fuel in existing power plants with Co-Firing technology, including methods for biomass pre-treatment.

## 2. CO-FIRING IN POWER PLANT

Co-firing technology was first used in Alaska, USA by using a mixture of coal and wood chips to produce steam in a grate fired boiler (Sampson et al., 1991). The constraints faced at that time were the difficulty of making a homogeneous mixture of coal and wood chips and the limited capacity of the grate fired boiler to obtain a larger mix flow rate. Then, several power plants have tried to use co-firing technology with various methods in order to achieve the expected performance targets, especially reducing the impact on the environment by using biomass as a renewable energy source. (Sami et al., 2001) (Baxter, 2005). Several studies on co-firing biomass with coal showed that production costs using biomass are more expensive than coal but the use of biomass can significantly reduce environmental impacts, especially CO<sub>2</sub> reduction. (Agbor et al., 2016) (Basu et al., 2011) (Loha et al., 2020). In fact, a combination of co-firing with carbon capture and storage was carried out to reduce the maximum impact of combustion CO<sub>2</sub> (Yang et al., 2019). Thus, it is necessary to analyze in depth co-firing technology in power plants, constraints in the use of co-firing technology in power plants, and biomass pre-processing technology for co-firing in power plants to obtain optimal conditions and the lowest impact on the environment.

There were 3 types of co-firing technology, namely direct co-firing, indirect co-firing and parallel co-firing. The direct co-firing type is the simplest type with the lowest investment because in this type, coal and biomass feed directly into the boiler unit without converting the biomass in a particular unit. (Suárez-Ruiz et al., 2018; van Loo & Koppejan, 2012). In addition, the direct co-firing type was the most effective type to reduce the greenhouse effect (GHG) of coal-fired power plants. (Roni et al., 2017) because the process can directly burn biomass. The performance of direct co-firing combustion was better because the high volatile matter content of biomass will improve the combustion process (Suárez-Ruiz et al., 2018)

In the direct co-firing type, it can be done in the first way, namely the flow of coal and biomass was prepared separately and entered through their respective routes or the second way was coal and biomass were mixed and prepared before feeding to the boiler. (Tillman, 2000). The first method was done because biomass has different qualities from coal so that combustion was separated for biomass and coal, while the second method was done by mixing coal as fuel by first improving the quality of the biomass so that combustion stability can be maintained (Karampinis et al., 2014). The problem in the direct co-firing type was the occurrence of ash deposition and corrosion because the quality of the biomass was very heterogeneous (Loha et al., 2020) (Priyanto et al., 2017) (Aviso et al., 2019). Some biomass contains large amounts of ash and a high composition of Potassium (K) and Calcium (Ca) in the ash. These components cause ash deposition so that biomass with a low ash content was preferred for co-firing (Niu et al., 2016) (Priyanto et al., 2016). Another way that can be done by checking the ash

fusion temperature (AFT) for some biomass and then blending between low and high AFT biomass in a certain proportion. (Yao et al., 2020).

Indirect co-firing technology was carried out by thermal conversion of biomass into producer gas through gasification technology. The producer gas was used as fuel in the power plant boiler along with burning coal. By separating the biomass conversion process, ash deposit and corrosion problems not occur in the boiler unit of the power plant (Dai et al., 2008). But this indirect technology will be difficult to implement in existing power plants because of the addition of a gasification unit that requires high costs and a large area (Basu et al., 2011). Thus, direct co-firing can be the main alternative by reducing the potential for ash deposition and corrosion. This can be done by using pre-treatment of biomass so that the acid content in the biomass can be removed to reduce the potential for corrosion and the use of biomass with high AFT and low ash content.

Generally, coal power plants use a pulverized combustion (PC) combustion system. The type of PC coal combustion can be carried out cofiring provided that the maximum water content of biomass was 2% and the size of the biomass was less than 10 mm (Ali Sayigh, 2012). Generally, the water content of biomass was above 20% and even above 60% (Basu, 2018) (Samuelsson et al., 2006) (Vassilev et al., 2010). High water content in biomass can reduce the energy value and cause problems in transporting biomass to the combustion chamber due to the potential for agglomeration of biomass (Motta et al., 2018; Ungureanu et al., 2018). Thus the water content of biomass must be removed to facilitate the process of utilizing biomass as fuel in a power plant co firing.

The process of removing water content from biomass can be done by drying. A drying technology that is suitable for large quantities of biomass and good quality results using a fluidized bed dryer. By using a fluidized dryer had high heat and mass transfer, the contact between hot gas and biomass was intensive and the resulting product yield was uniform. (Verma et al., 2017).

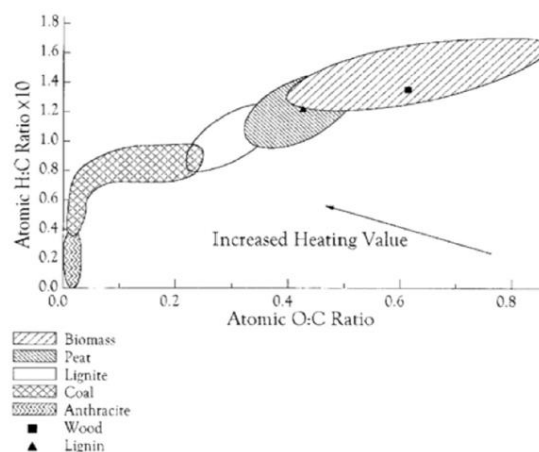


Fig 2 Van Krevelen Diagram of Solid Fuels (McKendry, 2002)

The difference in physical properties between coal and biomass becomes an obstacle in the direct use of biomass as a fuel. The energy content of coal is 25000 kJ / kg, while biomass is around 16000 kJ / kg (Demirbaş, 2003). The difference in energy content between coal and biomass because biomass has a low fixed carbon content and a high water content. Then the elemental content of C, H and O between coal and biomass was also significantly different as seen in the Van Krevelen diagram (Fig. 2). In the diagram, the ratio of the element O to C for biomass is very high above 0.6, while coal is below 0.4 to close to 0. Then the ratio of the element H to C for biomass reaches 0.14 while coal is lower below 0.12. This showed that biomass has a high oxygen and low carbon content.

Upgrading the biomass for fuel in co-firing technology must be carried out so that the characteristics of the biomass are closer to coal. There are several technologies for upgrading from biomass with chemical (leaching), thermal (drying and torrefaction), and mechanical (grinding and pellet) systems. There was a technology that can be applied, namely torrefaction to remove water content and part of the volatile matter. The torrefaction technology can also be combined with drying, grinding and pellet technology in an integrated manner (Kumar et al., 2017; Mobini et al., 2014).

### 3. BIOMASS TORREFACTION

Torrefaction was a biomass thermochemical process in the temperature range 200-300°C without involving oxygen (Bergman et al., 2005). The stages for the torrefaction process (Fig 3) can be seen in Table 1 (Ribeiro et al., 2018)

Table 1. Stages of Biomass Torrefaction

Phases	Description
Initial Heating	Biomass is heated until the drying temperature
Drying	The temperature (100°C) holds constant until the critical moisture content is reached
Post-drying	The biomass is heated to 200°C
Torrefaction	This stage is operated under torrefaction temperature
Cooling	The torrefied biomass is cooled from torrefaction temperature to room temperature.

The most important stage in the biomass torrefaction process is the torrefaction stage with the holding time at the torrefaction temperature. At the torrefaction stage, there was a loss of volatile matter which has potential energy when it is burned, so it is necessary to control the torrefaction temperature. Then holding time at the torrefaction temperature was needed so that not a lot of combustible gas was produced in the torrefaction process carried away in the gas stream. (Pimchuai et al., 2010).

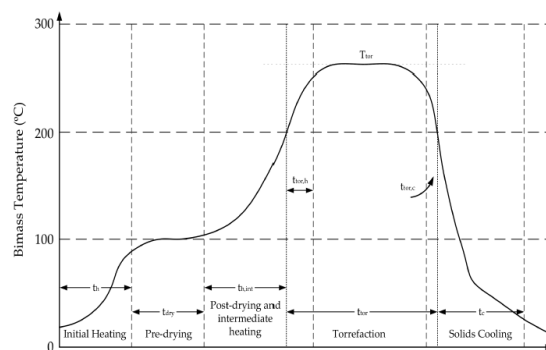


Fig 3 Schematic description of the different torrefaction stages (Ribeiro et al., 2018)

The torrefaction of biomass will lose about 30% of mass and 10% of energy loss so that the energy density of the biomass product increases by about 30% from the initial biomass condition (Fig. 4). The increase in energy density (MJ / kg) for the torrefaction of biomass is due to part of the hydrogen and oxygen content released from the biomass and carried into the gas stream (Park & Jang, 2012). Thus the torrefaction biomass will experience an increase in heating value and several other studies, the heating value can reach 7000 kcal / kg. (A. Irawan et al., 2019)(A. Irawan et al., 2017).

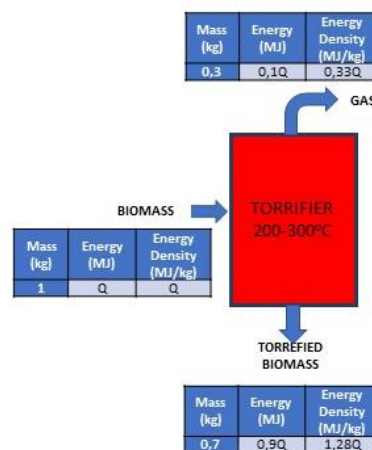


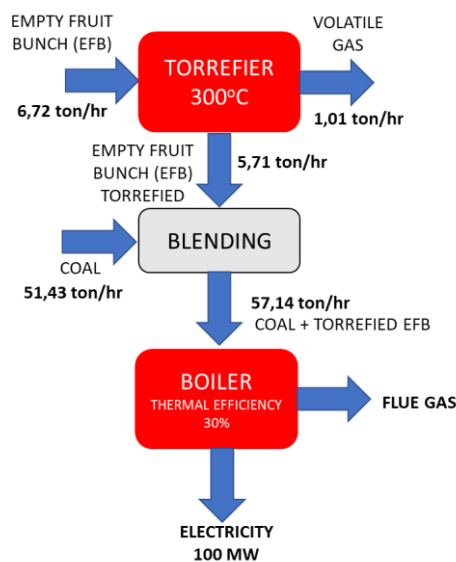
Fig 4 Typical of Mass and Energy Balance of Biomass Torrefaction (Basu, 2018)

Some types of biomass are difficult to grind because the cellulose component of the biomass was located in the hemicellulose matrix and stored in the lignin layer. (Chen et al., 2011). By torrefaction, part of the hemicellulose will come out and the cell walls in the biomass will be destroyed so that the torrefaction biomass will be easy to grind (Chen et al., 2015).

Generally, biomass has a high water content due to the ease absorbs water (hygroscopic). (Andersson & Tillman, 1989). Several studies with torrefaction showed that torrefaction biomass was hydrophobic because saturated water decreases by up to 73% (Felfli et al., 2005)(Anton Irawan et al., 2015). Due to the fact that during the harvest period, large amounts of biomass can be produced, so the hydrophobic nature is important for torrefaction biomass to be stored for a long time.

Fresh EFB had heating value of 17.43 MJ/kg or 4150 kcal/kg. Generally, the coal used for power generation was low rank coal with a heating value of 4500-5000 kcal/kg. Thus, there was a difference in the calorific value between coal and EFB of 350-850 kcal/kg. This difference can be reduced by carrying out the torrefaction process at a temperature of 573 K which can increase the calorific value of the torrefaction biomass up to 20% or to 5000 kcal/kg with a mass loss of about 15%. At a lower torrefaction temperature of 523 K, the heating value of the torrefaction biomass product increases by 5% with a maximum mass loss of 10% (Uemura et al., 2013).

Figure 5 showed direct co-firing with torrefaction biomass for a 100 MW power generation system with a thermal efficiency of 30%. For sample co-firing system used 10% of EFB torrefaction biomass and 90% of the energy needs of coal, the required fresh EFB biomass was 6.72 ton/hour to produce 5.71 ton/hour of EFB biomass torrefaction at temperatures of 300°C. Generally, oil palm mills process 25 ton/ hour of oil palm fruit bunches (FFB) to produce fresh fruit bunches of 5.25 ton/hour. Thus 5.71 ton/hour of torrefaction EFB can be obtained from two palm oil mills.



**Fig 5** Direct Co-Firing Biomass Empty Fruit Bunch (EFB) 10 % and 90 % Coal in 100 MW Power Plant with 30 % Efficiency Thermal

Many palm oil mills were located in Sumatra, Borneo and Celebes. In order to reduce logistics costs, the EFB torrefaction biomass produced from the palm oil mill can be integrated with the nearest power plant from the location of the palm oil mill. The government must encourage cooperation between palm oil mills and power plants in implementing Co-Firing Technology.

#### 4. CONCLUSION

Biomass co-firing technology for power generators in Indonesia can be implemented with the potential for abundant biomass in Indonesia. The constraints of differences in biomass quality can be uniformed using torrefaction so that the quality of combustion in the boiler with the presence of torrefaction biomass as fuel

with coal still performs well. One of the biomass that has great potential to be used in a co-firing system was EFB that produced from crude palm oil processing plant. Direct-cofiring technology with EFB torrefied can be implemented in power plants that are located close to palm oil mills in order to reduce transportation costs.

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