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Greenhouse Gas Emission Reduction Potential for Power Generation in Indonesia Using Boiler Advanced Technology Application

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Abstract. Energy consumption in Indonesia is still dominated by coal, especially for power generation. Coal is one of the sources for air pollution and carbon emissions. Based on Indonesia Energy Outlook 2019, installed capacity for power generation in Indonesia is still dominated by fossil energy, especially coal, which is almost 50% on mix energy, followed by gas 29%, Oil 7% and renewable energy 14%. Coal will have a major role in the installed power generation in Indonesia until 2025 [1]. The utilization of clean coal technology seems a strategic policy in Indonesia for emission reduction in the power sector. The calculation method based on coal ton conversion into CO₂ ton emission on methodological tool of UNFCC “Tool to calculate project leakage CO₂ emission from fossil fuel combustion” will be used. The data is also given based on IPCC standard for NCV for fuel type and CO₂ emission factor for fuel type. This paper will review utilization of clean coal technology using the advanced technologies include super-critical and ultra-super-critical for coal fired steam power plant in Indonesia furthermore the potential reduction of greenhouse gas emission. The result is potential of CO₂ gas reduction in Indonesia approximately 6,140,394.90 ton CO₂ and it’s equal of 6.14 MTCO₂ per year.

INTRODUCTION

In 2019, the installed capacity of power generation in Indonesia is about 64,5 GW and most of them still use fossil fuel especially coal. Coal fired steam power plant (CFSP) still dominates on mix energy in Indonesia, about 50% power generation in Indonesia use coal as fuel. Figure 1 shows energy mix in Indonesia for power generation [1].

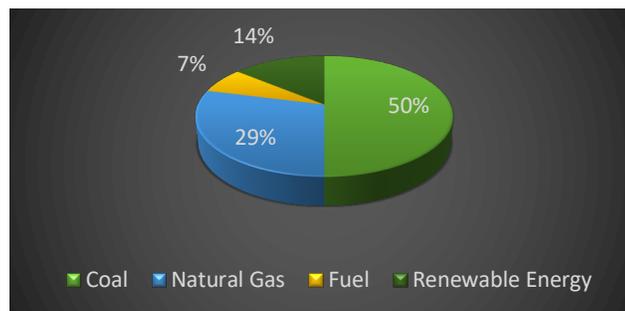


FIGURE 1. Installed Capacity of Power Generation in Indonesia Based on Energy Used

Based on RUPTL data 2019-2028, coal also have a major role for the new installed power generation planning in the future until 2028, because the price and the availability of coal energy still good enough. Furthermore, the dominated coal as fuel consumption for power generation will increase the greenhouse gas emission from power sector.

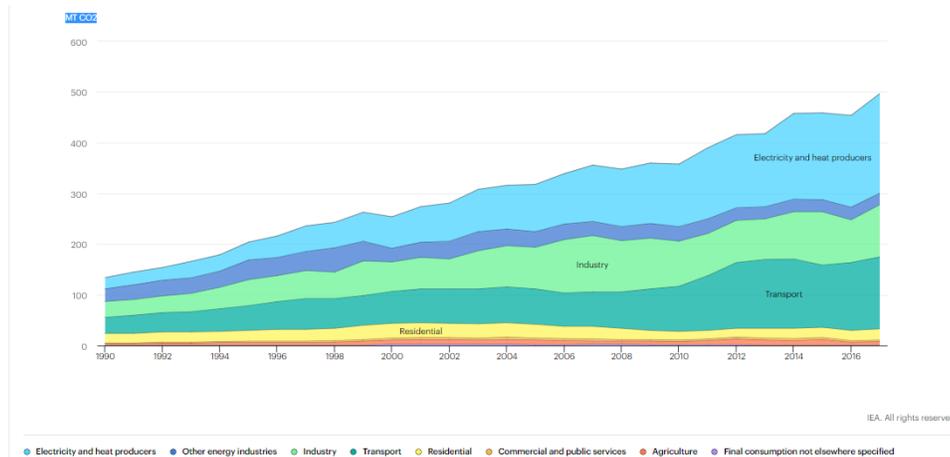


FIGURE 2. CO₂ Emission by Sector in Indonesia 1990 – 2017
SOURCE: IEA

Based on IEA data which is shown in Figure 2, it can be concluded that electricity is the biggest factor for CO₂ emission in Indonesia. The government have made some policy related with Paris agreement which result the UNFCCC-21 conferences in Paris 2015 [2]. Indonesian government also have issued UU No. 16 2016 which Indonesia will contribute to reduce greenhouse gas emission 29% in 2030 through several program, include:

- a) Development renewable energy for power generation.
- b) Alternative Fuel.
- c) Development low carbon technology and efficient technology.

Some policy has to be decided to control CO₂ emission by government. This plan should not only include a long-term strategy, but also a decision in the current situation to ensure that it will become a correct policy. Clean coal technology (CCT) will be the strategic program in Indonesia to reduce the carbon emission because coal still have important role in power generation and it's the biggest percentage in mix energy. CCT include of several technologies which will improve the efficiency of coal energy.

Clean coal technology is needed for improving the coal energy output become friendly for environment and become cleanly technology. Based on clean coal technology processing in power generation, it can be divided into 3 section :

- a) Pre combustion : The technology is used for improving calories value of coal, i.e. coal drying, IGCC (Integrated Gasification Combined Cycle).
- b) Combustion : The technology is used for improving boiler efficiency in combustion process, i.e. the usage of super critical boiler, ultra super critical boiler and advanced ultra super critical boiler (still going on research).
- c) Post combustion : The technology is used for reducing greenhouse gas emission after combustion, i.e. the use of carbon captured storage (CCS).

The objective of this paper is to show how can be clean coal technology reduce the CO₂ emission in combustion process for power generation through using super critical boiler, ultra-super critical boiler and the potential CO₂ emission reduction by CCT.

EMISSION STUDY IN INDONESIA

CO₂ Emission in Indonesia

Based on IEA data, CO₂ emission increase continuously in Indonesia, as shown in Figure 3.

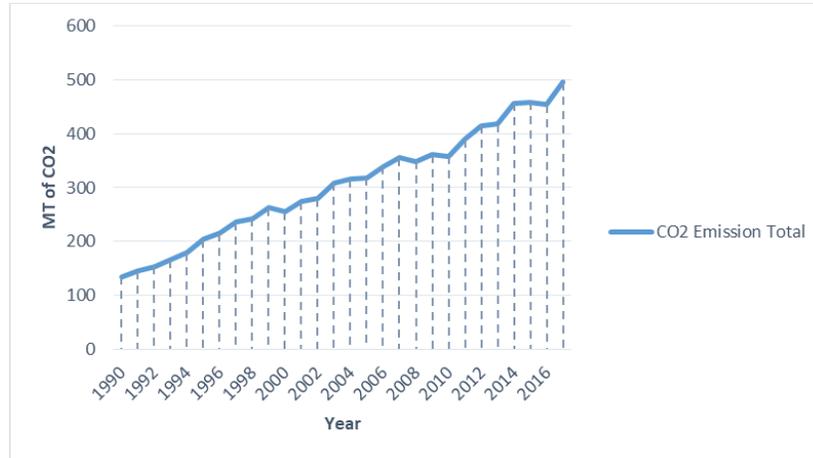


FIGURE 3. Total of CO₂ Emission in Indonesia by Year

In Figure 3, it can be explained that total CO₂ emission in 2017 is about total emission 496 MT of CO₂, this amount describes the total emissions from several sectors including electricity sector. The electricity sector is about 196 MT of CO₂ emissions, so that almost 40% which give the effect to CO₂ emissions from the electricity [2].

Figure 4 shows the source of energy which is contributes to CO₂ emissions from electricity sector.

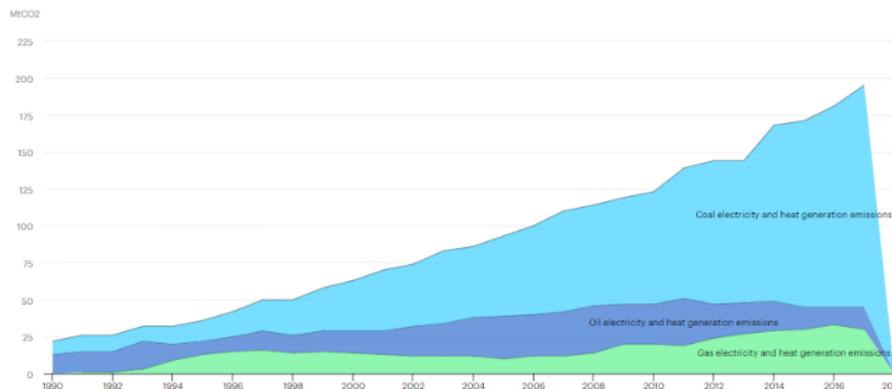


FIGURE 4. Source of Energy Contributes to CO₂ Emission

From Figure 4, it can be concluded that the use of coal gives the largest CO₂ emissions for electricity sector. Coal is about 150 MT of CO₂, it's means that 76% CO₂ emissions from the electricity sector is caused by the use of coal as power generation fuel [2]. To solve this problem the government has taken strategic policy, one of them is using CCT technology in the power generation especially for big scale of coal fired steam power plant.

Impact of Coal Usage

The concern of the coal usage is the environmental impact due to pollutant emissions (pollutants) such as SO₂, NO_x and SPM (Suspended Particulate Matters), as well as CO₂ greenhouse gas emission. Coal has the highest carbon

19

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21

emission factor among the other fossil energy. The highest carbon emission factor from coal indicates that using coal can produce many of CO₂ greenhouse gas emissions. CO₂ greenhouse gas emission increasing in the atmosphere will cause global warming [3].

CLEAN COAL TECHNOLOGY IN COMBUSTION PROCESS

Clean coal technology which is used in combustion process is the technology for increasing boiler efficiency, example super critical boiler and ultra-super critical boiler usage. Conventional boiler i.e sub critical boiler, water is heated at subcritical pressure (below 22,1 Mpa), the temperature will increase until evaporate starts. When the water boils, there are two phase liquid and gas, each of them has different densities until constant temperature known as saturation temperature [4].

If all the liquid evaporates change into a gas phase, the temperature of the steam will increase continuously at a constant pressure known as superheated steam. Sub critical boiler specifically still separate the liquid and gas phase. The separation process is in the steam drum which equipped with a series of cyclones and baffles for the separation of the liquid phase from the gas [5].

In super critical boiler, water is heated at a constant pressure above a critical pressure so that there is no difference between gas and liquid, because the mass of density is the same. In super critical boiler there are no stages of water phase so that it requires a separation. There are no drum in the boiler. Boiler use superheater steam at once. Feed water is pumped by the boiler feed pump until the water through the heating stage in the boiler and the steam flow directly to the steam turbine without recirculation. In actual conditions, the transition from liquid into steam in super critical boiler depend on conditions. It means that the boiler load changing and process pressure can optimize the amount of liquid and gas area for efficient heat transfer [3].

COAL FIRED STEAM POWER PLANT WITH SUPER CRITICAL BOILER IN INDONESIA

Based on RUPTL 2019 – 2028 data, coal fired steam power plant are still becoming a major role in the national electricity mix. For keeping the balance between the development of clean energy, the government has committed to implement clean coal technology with using super critical or ultra-super critical in the power generation.

Now, there are eight existing coal fired steam power plants which have been operating using super critical and ultra-super critical technology with a total capacity of 6,455 MW. Eight coal power plants are consisting of coal fired steam power plant (PLTU Cirebon (660 MW), PLTU Paiton 3 (815 MW), PLTU Adipala (660 MW), PLTU Banten 2 (660 MW), PLTU Cilacap 3 (660 MW) which have been operating using super critical technology. There are three power plant which have been operating using ultra super critical technology, including PLTU Cilacap 4 (1000 MW), PLTU Jawa 7 (1000 MW) and PLTU Jawa 8 (1000 MW).[6]

The government also has a program to develop coal fired plant using ultra super critical boiler technology in nine locations on Java with a total capacity of 11,751 MW until 2028. Nine coal fired power plants, based on RUPTL 2019 – 2028 data nine power plants consist of PLTU Jawa Tengah (2x950 MW), PLTU Jawa 1 (924 MW), PLTU Jawa 4 (2x1000 MW), PLTU Jawa 5 (1000 MW), PLTU Jawa 7 (2x991 MW), PLTU Jawa 8 (945 MW), PLTU Jawa 9-10 (2x1000 MW) and PLTU Indramayu 4 (1000 MW).[7]

EMISSION REDUCTION CALCULATION

Power plant efficiency can be improved by using the super critical boiler, so that this boiler technology can be applied for any power plant in order to get some output with good efficiency and low emission also. Power plant efficiency (η %) is the comparison between electrical energy produced with fuel energy needed, commonly referred as percentage. Heat rate (HR) which is other parameter is usually used in efficiency calculation for power plant also. Heat rate is the rate of fuel energy needed to generate unit of electricity energy (btu/kWh, kJ/kWh or kcal/kWh) [8].

Research Data

Based on reference book New Coal Fired Power Plant Performance and Cost Estimates from Sargent&Lundy, some data can be used for the calculation analysis, include:[9]

Boiler Type Based on Temperature and Pressure

Based on pressure, boiler can be classified as Table 1.

TABLE 1. Boiler Classification Based on Pressure and Temperature

Plant Type	Main Steam Pressure (psia)	Main Steam Temperature (°F)	Reheat Steam Temperature (°F)
SubC (Sub Critical)	2,535	1,050	1,050
SC (Super Critical)	3,690	1,050	1,100
USC (Ultra Super Critical)	3,748	1,100	1,100
AUSC (Advanced Ultra Super Critical)	4,515	1,300	1,300

The higher pressure and temperature of the boiler, the faster coal burning process so that it will improve power plant efficiency. The high of temperature and pressure made increase the material quality installed for the equipment also, consequently it also increases EPC cost of power plant [10].

Boiler Type Based on Temperature and Pressure

Boiler performance simulation is measured in 59 °C and relative humidity 60%. Boiler performance estimate in Btu/kWh and % is shown in Table 2 and Table 3.

TABLE 2. Boiler Performance Estimate (Btu/kWh)

Plant Type	MW Gross (Btu/kW net)		
	400 MW	600 MW	900 MW
	Bituminous		
SubC (Sub Critical)	9,349	9,302	9,291
SC (Super Critical)	9,058	9,017	8,990
USC (Ultra Super Critical)	8,924	8,874	8,855
AUSC (Advanced Ultra Super Critical)	8,349	8,305	8,279

TABLE 3. Boiler Performance Estimate (100%)

Plant Type	MW Gross (%)		
	400 MW	600 MW	900 MW
	Bituminous		
SubC (Sub Critical)	36,5	36,7	36,7
SC (Super Critical)	37,7	37,8	38,0
USC (Ultra Super Critical)	38,2	38,4	38,5
AUSC (Advanced Ultra Super Critical)	40,9	41,1	41,2

Power Generation EPC Cost Estimation

Power generation EPC cost including of boiler system with additional equipment i.e ESP, DeNox and FGD shown in the Table 4.

TABLE 4. Total EPC Cost Power Generation

Plant Type	MW Gross (\$/kW net)		
	400 MW	600 MW	900 MW
	Bituminous		
SubC (Sub Critical)	4,523	3,844	3,190
SC (Super Critical)	4,686	3,982	3,262
USC (Ultra Super Critical)	4,835	4,109	3,362

Coal Ton Become CO₂ Ton Calculation

Coal ton conversion into CO₂ ton emission based on methodological tool of UNFCCC “Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion”, with the formula [11]:

$$CO_2 = Total\ of\ Coal\ x\ NCV\ x\ CO_2\ Emission\ Factor \tag{1}$$

Unit measurement:

- Total of coal = Kg
- NCV (Net Color Value) = TJ/Gg
- CO₂ emission factor = Kg CO₂/TJ

NCV Value and CO₂ Emission Factor

Based on IPCC, the data shown in Table 5 and Table 6.

TABLE 5. NCV for Fuel Type

Fuel Type	Net Caloric Value (TJ/Gg)	Lower		Upper
Crude Oil	42,3	40,1		44,8
Gas/Diesel Oil	43,0	41,4		43,4
Other Bituminous Coal	25,8	19,9		30,5
Sub-Bituminous Coal	18,9	11,5		26,0

TABLE 6. CO₂ Emission Factor for Fuel Type

Fuel Type	Default Carbon Content (kg/GJ)	Default Carbon Oxidation Factor	Effective CO ₂ Emission Factor (kg/TJ)		
			Default Value	95% Confidence Interval	
				Lower	Upper
	A	B	C=A*B*4*4/12*1000		
Crude Oil	20,0	1	73,300	71,100	75,500
Gas/Diesel Oil	20,2	1	74,100	72,600	74,800
Other Bituminous Coal	25,8	1	94,600	89,500	99,700
Sub-Bituminous Coal	26.2	1	96,100	92,800	100,000

Coal Type

Coal type which is used in simulation is bituminous type. This coal have caloric value above 5,700 kcal/kg.

Data Calculation

Coal Consumption Calculation per Year

It's assumed, there coal type is bituminous with caloric value 5700 kcal/kg and the power plant capacity factor is 80%.

- a) Power plant with 400 MW capacity

$$\text{Electricity Production (MWh)} = 400\text{MW} \times 0.8 \times 24 \text{ hours} \times 30 \text{ days} \times 12 \text{ month} = 2,764,800 \text{ MWh}$$

$$\text{Coal Consumption (Ton)} = \frac{\text{Electricity Production} \times \text{FC}}{\text{Caloric Value}} \tag{2}$$

- *SubC Boiler Type Consumption*

$$= \frac{2,764,800 \times 9,349}{5,700} = 4,534,757.05 \text{ Ton}$$
- *SC Boiler Type Consumption*

$$= \frac{2,764,800 \times 9,058}{5,700} = 4,393,606.74 \text{ Ton}$$
- *USC Boiler Type Consumption*

$$= \frac{2,764,800 \times 8,924}{5,700} = 4,023,026.53 \text{ Ton}$$

The calculation can be summarized into this table below.

TABLE 7. Coal Consumption Calculation Per Year for Power Plant Capacity 400 MW

Fuel Type	Coal Consumption (Ton)
SubC Boiler	4,534,757.05
SC Boiler	4,393,606.74
USC Boiler	4,023,026.53

- b) Power plant with 600 MW capacity

$$\text{Electricity Production (MWh)} = 600\text{MW} \times 0.8 \times 24 \text{ hours} \times 30 \text{ days} \times 12 \text{ month} = 4,147,200 \text{ MWh}$$

- *SubC Boiler Type Consumption*

$$= \frac{4,147,200 \times 9,302}{5,700} = 6,767,939.37 \text{ Ton}$$
- *SC Boiler Type Consumption*

$$= \frac{4,147,200 \times 9,017}{5,700} = 6,560,579.37 \text{ Ton}$$
- *USC Boiler Type Consumption*

$$= \frac{4,147,200 \times 8,874}{5,700} = 6,456,535.58 \text{ Ton}$$

The calculation can be summarized into this table below.

TABLE 8. Coal Consumption Calculation Per Year for Power Plant Capacity 600 MW

Fuel Type	Coal Consumption (Ton)
SubC Boiler	6,767,939.37
SC Boiler	6,560,579.37
USC Boiler	6,456,535.58

- c) Power plant with 900 MW capacity
 $Electricity\ Production\ (MWh) = 900MW \times 0.8 \times 24\ hours \times 30\ days \times 12\ month = 6,220,800\ MWh$
- *SubC Boiler Type Consumption*

$$= \frac{6,220,800 \times 9,291}{5,700} = 10,139,904\ Ton$$
 - *SC Boiler Type Consumption*

$$= \frac{6,220,800 \times 8,990}{5,700} = 9,811,402.11\ Ton$$
 - *USC Boiler Type Consumption*

$$= \frac{6,220,800 \times 8,855}{5,700} = 9,664,067.37\ Ton$$

The calculation can be summarized into this table below.

TABLE 9. Coal Consumption Calculation Per Year for Power Plant Capacity 900 MW

Fuel Type	Coal Consumption (Ton)
SubC Boiler	10,139,904
SC Boiler	9,811,420.11
USC Boiler	6,456,535.58

Reduction Coal Consumption for *Super Critical and Ultra Super Critical* Boiler

- a) Power plant with 400 MW capacity
- *Deviation SC Boiler*

$$= SubC\ Consumption - SC\ Consumption$$

$$= 4,534,757.05 - 4,393,606.74$$

$$= 141,150\ Ton$$
 - *Deviation USC Boiler*

$$= SubC\ Consumption - SC\ Consumption$$

$$= 4,534,757.05 - 4,023,026.53$$

$$= 511,731\ Ton$$
- b) Power Plant with 600 MW capacity
- *Deviation SC Boiler*

$$= SubC\ Consumption - SC\ Consumption$$

$$= 6,767,939.37 - 6,560,579.37$$

$$= 207,360\ Ton$$
 - *Deviation USC Boiler*

$$= SubC\ Consumption - SC\ Consumption$$

$$= 6,767,939.37 - 6,456,535.58$$

$$= 311,404\ Ton$$
- c) Power plant with 900 MW capacity
- *Deviation SC Boiler*

$$= SubC\ Consumption - SC\ Consumption$$

$$= 10,139,904 - 9,811,402.11$$

$$= 328,502\ Ton$$
 - *Deviation USC Boiler*

$$= SubC\ Consumption - SC\ Consumption$$

$$= 10,139,904 - 9,664,067.37$$

$$= 475,837\ Ton$$

CO₂ Reduction for SubC Boiler

The amount of CO₂ reduction is got from comparison between super critical boiler technology and ultra super critical boiler technology with sub critical boiler technology. CO₂ reduction can be obtained by converting fuel differences between SC boiler and USC boiler with SC boiler into CO₂ emissions using the UNFCC methodological tool “tool to calculate project or leakage CO₂ emissions from fossil fuel combustion. NCV value 5700 kcal/kg is converted become 23.8 TJ/gr and use fuel emission value factor of 92,800 kg/TJ according to the reference in Table VI.

- a) Power plant with 400 MW capacity
 - *Emissions Reduction SC Boiler (tCO₂)*
 $= \text{Differences SC} \times \text{NCV} \times \text{Emission Factor}$
 $= 141,150 \times 23.8 \times 92,800 \times 10^{-6}$
 $= 311,750.23 \text{ tCO}_2$
 - *Emissions Reduction USC Boiler (tCO₂)*
 $= \text{Difference USC} \times \text{NCV} \times \text{Emission Factor}$
 $= 511,731 \times 23.8 \times 92,800 \times 10^{-6}$
 $= 455,305.32 \text{ tCO}_2$
- b) Power plant with 600 MW capacity
 - *Emissions Reduction SC Boiler (tCO₂)*
 $= \text{Difference SC} \times \text{NCV} \times \text{Emission Factor}$
 $= 207,360 \times 23.8 \times 92,800 \times 10^{-6}$
 $= 457,983.59 \text{ tCO}_2$
 - *Emissions Reduction USC Boiler (tCO₂)*
 $= \text{Difference USC} \times \text{NCV} \times \text{Emission Factor}$
 $= 311,404 \times 23.8 \times 92,800 \times 10^{-6}$
 $= 687,778.87 \text{ tCO}_2$

RESULT AND DISCUSSION

Simulation for Power Plant in Indonesia

There are some power plants which have been operated by using supercritical boiler technology and ultra-super critical boiler technology in Indonesia. There are five power plant operate with super critical and three power plant operate with ultra-super critical. Table 7 shows SubC boiler coal consumption, Table 8 shows SC/USC boiler coal consumption, Table 9 shows the simulation for power plant in Indonesia in order to save coal fuel and CO₂ emission reduction.

TABLE 10. SubC Boiler Coal Consumption

Power Plant	Capacity MW(SC/USC)	Electricity Production (MWh)	SubC Coal Consumption (Ton)
PLTU Cirebon	660 (SC)	4,561,920	7,444,733
PLTU Paiton 3	815 (SC)	5,633,280	9,193,118
PLTU Adipala	660 (SC)	4,561,920	7,444,733
PLTU Banten 2	660 (SC)	4,561,920	7,444,733
PLTU Cilacap 3	660 (SC)	4,561,920	7,444,733
PLTU Cilacap 4	1000 (USC)	6,912,000	11,266,560
PLTU Jawa 7	1000 (USC)	6,912,000	11,266,560
PLTU Jawa 8	1000 (USC)	6,912,000	11,266,560

TABLE 11. SC/USC Boiler Coal Consumption

Power Plant	Capacity MW(SC/USC)	Electricity Production (MWh)	SubC Coal Consumption (Ton)
PLTU Cirebon	660 (SC)	4,561,920	7,216,637
PLTU Paiton 3	815 (SC)	5,633,280	8,911,454
PLTU Adipala	660 (SC)	4,561,920	7,216,637
PLTU Banten 2	660 (SC)	4,561,920	7,216,637
PLTU Cilacap 3	660 (SC)	4,561,920	7,216,637
PLTU Cilacap 4	1000 (USC)	6,912,000	10,737,853
PLTU Jawa 7	1000 (USC)	6,912,000	10,737,853
PLTU Jawa 8	1000 (USC)	6,912,000	10,737,853

TABLE 12. Coal Fuel Saving and CO₂ Emission Reduction

Power Plant	Capacity MW(SC/USC)	Coal Saving (Ton)	CO ₂ Reduction (tCO ₂)
PLTU Cirebon	660 (SC)	228,096	503,781.95
PLTU Paiton 3	815 (SC)	281,664	622,094.38
PLTU Adipala	660 (SC)	228,096	503,781.95
PLTU Banten 2	660 (SC)	228,096	503,781.95
PLTU Cilacap 3	660 (SC)	228,096	503,781.95
PLTU Cilacap 4	1000 (USC)	528,707	1,167,724.24
PLTU Jawa 7	1000 (USC)	528,707	1,167,724.24
PLTU Jawa 8	1000 (USC)	528,707	1,167,724.24

From the Table 9, it is known that the potential of CO₂ gas reduction in Indonesia is about 6,140,394.90 ton CO₂ equal of 6,14 MTCO₂ per year.

Data Analysis

Based on the calculation data, it is informed that by using boiler technology which has been better than Sub Critical boiler in currently in use, will reduce coal fuel consumption so that it will also reduce coal fired steam power plant emissions. The potential coal fuel consumption reduction per year can be shown in the following Figure 5.

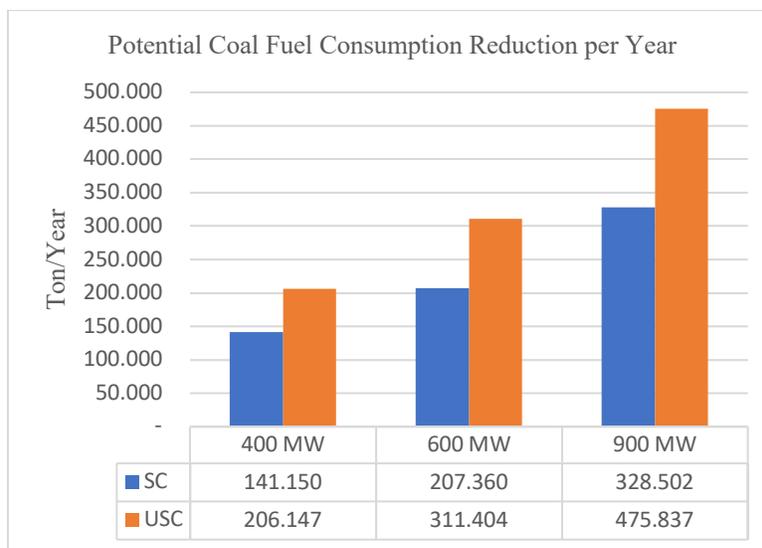


FIGURE 5. Potential Coal Fuel Consumption Reduction per Year

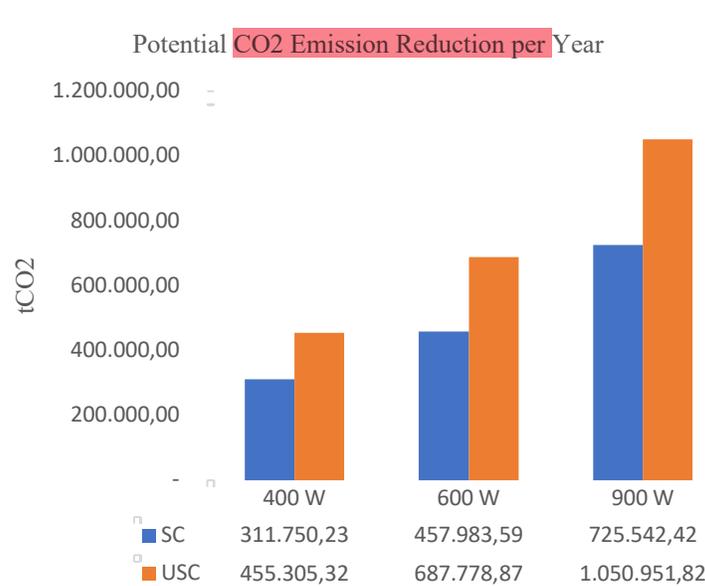


FIGURE 6. Potential CO₂ Emission Reduction per Year

The potential CO₂ emissions reduction can be shown in the Figure 6. It is known that the biggest potential CO₂ emission reduction is using ultra super critical boiler technology. The higher power plant capacity, the higher CO₂ emissions reduction will be produced.

CONCLUSION

There are some methods to reduce CO₂ emission with clean coal technology, i.e in Pre-Combustion process (with IGCC technology), Combustion Process (with boiler advanced technology include of Super Critical Boiler and Ultra Super Critical Boiler), and Post Combustion Process (with carbon captured storage). In this paper, clean coal technology method with boiler advanced technology will be used to reduce CO₂ emission. The potential CO₂ gas reduction in Indonesia is about 6,140,394.90 ton CO₂ equal with 6,14 MTCO₂ per year and 4%. It results from eight power plant existing which have been operated in Indonesia. The power plant which can be used with this boiler technology only the large capacity above 400 MW for the best potential results.

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