ISSN No:-2456-2165

Trends of Clean Coal Technologies for Power Generation Development in Indonesia

Andri Gunawan, Suyono Thamrin, Arifuddin Uksan
Energy Security Department, Defense Management Faculty,
Indonesia Defense University Bogor, West Java, Indonesia

Abstract:- There is an inseparable relationship between the use of technology and environmental damage. To overcome environmental damage, the world's population must make various efforts, especially the use of the latest technology by utilizing environmentally friendly fossil fuels. Coal is one of the fossil fuels and most of the coal is used for power generation. Power plants that use coal as an energy source can cause increased pollutant emissions such as SO_2, NOx, CO_2 and others. Most of the power plants in Indonesia use coal as an energy source. The existence of the Paris Agreement which aims to reduce greenhouse gas emissions encourages the Indonesian government to reduce air emissions. Indonesia has coal reserves of 38.84 billion tons in 2021. With many power plants that use coal energy and Indonesia's very large coal reserves, technologies that can minimize pollution resulting from coal utilization are needed. One way that can be done to overcome this problem is to apply clean coal technology (Clean Coal Technologies) which can be classified according to the level of the energy production process at the time of power generation, including Pre-Combustion and Post-Combustion technologies. The technology used before the combustion stage is using FBC (Fluidized Bed Combustion) technology, coal gasification technology, MHD (Magnetic Hydrodynamic Technology), Fuel Cell Technology and IGCC Combination. The technology carried out after the combustion stage is using denitrification technology, dedusting technology, desulfurization technology and oxy-combustion system. In this study, the author will use a descriptive method with a qualitative approach, where the research intends to understand clean coal technologies that can be applied to power plants in Indonesia.

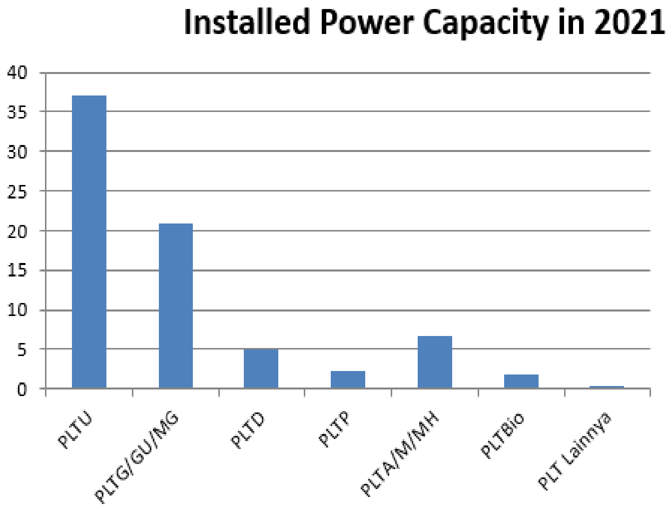
Keywords:- *Clean Coal Technologies; Pollutant; fossil fuels; Indonesia Power Generation.*

I. INTRODUCTION

The demand for electrical energy in Indonesia is increasing along with the increasing number of Indonesian people. Electrical energy consumption in September 2021 reached 187.78 terawatts per hour (TWh), the usage grew by 4.42% compared to last year in the same period [3]. According to the Ministry of Energy and Mineral Resources, in 2021 the need for electrical energy per capita will reach 1,123 kWh, this is an increase compared to last year. To maintain consumer electrical energy needs in boost the pace of the economy, the government has prepared a power plant with an installed capacity of 74 Giga Watt (GW) [9].

Most of the electricity companies in Indonesia are divided into two groups, namely power plants for public use and power plants for their interests. Most of the power plants used for public purposes are supplied by PT. Pembangkit Listrik Negara (PLN) and partly provided by private electric energy companies or often also called IPPs (Independent Power Producers) and also cooperatives. Power plants that are used for personal purposes are also called captive power which is managed by the private sector to fulfil all their business operational interests.

In 2021 the total installed capacity of PT. PLN reached 74 GW with a total electricity production of 187.78 terawatts per hour (TWh). The electricity production is generated from several power plants, as shown in graph 1



Graph 1: Indonesia's Electricity Production Capacity in 2021 [10]

Seen in Graph 1. above, a Steam Power Plant (PLTU) with size of 37 GW, Gas Power Plant (PLTG/GU/MG) with capacity of 5 GW, Diesel Power Plant (PLTD) with capacity of 2.3 GW, Power Plant Hydro Power (PLTA/M/MH) with capacity of 6.6 GW, Bio Power Plant (PLT Bio) with capacity of 1.9 GW and other Power Plants with a capacity of 0.4 GW. The total installed capacity of PT. PLN 2021 will reach 74 GW with a total electricity production of 187.78 terawatts per hour (TWh) [2].

Until now, the Indonesian government still relies on coal-fired power plants as the main energy source to meet consumer electricity needs. Indonesia's coal reserves are 38.84 billion tons, with average annual coal production of 600 million tons, assuming no new coal reserves are found, it is estimated that Indonesia's coal reserves are still 65 years old. [7].

The use of coal as a primary energy source in power generation and industry has the potential to cause an increase in pollutant emissions (polluting materials) such as NO_2, SO_2, and CO_2, for greenhouse gas (GHG) emissions in the form of carbon dioxide (CO_2) is an element that contributes greatly on greenhouse gas emissions [13].

Greenhouse gas emissions are a very important concern for countries around the world where on 31 October -13 November 2021 countries will hold a meeting in Glasgow, England to discuss climate change. The meeting stressed the importance of joint efforts in limiting the temperature rise to 1.5°C. The resulting document also reflects Indonesia's view on the importance of concretely increasing the seriousness of the agreed commitments and also the commitment of funding support from developed countries to developing countries [8].

There were four points generated in the meeting, among others:

- Accelerate the development of clean energy and energy efficiency.
- Accelerate technology and policy development to enable a free transition from energy-free generation to carbon recovery and storage.
- Stop issuing new permits and building coal-fired power plants that do not use carbon capture and storage technologies.
- Strengthen national and international efforts to provide financial, technical and social support for a just and comprehensive transition. [15].

This commitment will be one of the factors determining the achievement of the target of the full Paris Agreement meeting. This is in line with Indonesia's plan to reduce carbon emissions as part of climate change control actions. Efforts are needed to reduce greenhouse gas emissions from coal pollution, so the government through the Ministry of Energy and Mineral Resources is looking for innovations in the use of clean energy-based technology that is expected to optimize the use of coal in Indonesia. The use of clean coal technology aims to develop a thermal system that is much more environmentally friendly and efficient, namely obtaining the same energy, with much less coal input so that it has the potential to increase the availability of abundant and affordable energy resources.

Diversification of clean coal technology continues to be developed to obtain an efficient and environmentally friendly method of coal utilization for the process of generating electrical energy. Coal plants with Higher Efficiency and Low Emission (HELE) are the keys to Clean Coal Technologies (CCT) [16].

From the description above, it is clear that coal is likely to be used as fuel for power generation in the future. However, there are many obstacles to the use of coal including:

- The solid form of coal makes it difficult to carry out further processing.
- The natural content of coal has a large carbon element, causing CO_2 gas pollution when the coal is burned.
- The content of other elements in coal that are harmful such as sulphur and nitrogen.

To deal with the existing problems, the application of clean coal technology (Clean Coal Technologies) is classified based on the level of the energy production process during power generation, which includes technology before combustion (Pre-Combustion) and after combustion (Post-Combustion). The authors wish to describe Clean Coal Technologies that can be developed in Indonesia in the future so that optimal and environmentally friendly coal utilization can be achieved. the authors will use a descriptive method with a qualitative approach, where the research intends to understand clean coal technologies that can be applied to power plants in Indonesia.

II. CLEAN COAL TECHNOLOGY DEVELOPMENT

Coal is an energy source that harms the environment from exhaust emissions the use of coal. In the current condition, the development of new renewable energy technology is still unable to meet the demand for energy needs. So that to meet these energy needs, power plants sourced from coal energy are still the main choice to meet consumer energy needs. So that the application of technology to reduce pollutant emissions from the use of coal can be considered.

A. pre-combustion Technology

The technology for cleaning coal before the combustion process is carried out is by using the reaction of the fuel that functions as fuel to be mixed with oxygen or air to produce Synthesis gas (Syngas) or Fuel Gas which is mostly based on CO (Carbon Monoxide) and H2 (Hydrogen). Carbon Monoxide is reacted with steam in a catalytic reactor called a shift converter, to produce CO2 which has more hydrogen than simultaneously separated using physical and chemical absorption processes to produce hydrogen-rich fuel that can be used in many thermal generating technologies such as boilers, gas turbines, furnaces, engines and fuel cells.

Two ways to produce synthesis gas (syngas) are by adding steam (reaction 1) to the main fuel where this process is called steam reforming or by adding oxygen (reaction 2) to the main fuel or called partial oxidation.

Steam Reforming : CxHy + xH2O ↔xCO + (x + y/2) H2HCH4 = 206 kJ mol^{-1} (1)

Partialoxidation : CxHy + x/2O2 ↔xCO + (y/2) H2HCH4 = −36 kJ mol^{-1} (2)

In partial oxidation, most processes use oxygen obtained from the air separation process. Both reactions that use steam or oxygen in this process are called termed auto thermal reforming because the endothermic reforming reaction is balanced by exothermic partial oxidation. After syngas production, a Water Gas Shift (WGS) reaction occurs, by adding water vapour to convert CO into CO2 and H2. (3).

Water-Gasshift : CO + H2O ↔ CO2 + H2H = −41 kJ mol−1 (3)

ISSN No:-2456-2165

Using a conventional washing step, the CO2 is separated at ambient temperature. The hydrogen-rich gas will be used as a low-carbon fuel in the combined power plants of the Brayton + Rankine Cycle [4].

High pressure in the Water-Gassgift which produces steam gas can cause CO2 gas removal. The concentration of CO2 at the CO2/H2 inlet at the separation stage ranges from 15-60%, at a total pressure usually between 2 and 7 MPa meaning CO2 resulting from the separation and compression process requires less energy than the Post-Combustion process where the total pressure and CO_2 have a lower concentration [1]. The separated CO2 gas is then stored in the storage process. However, this lower energy requirement is offset by the energy required for reforming/gasification air separation and energy loss during the syngas temperature change process.

The Pre-combustion process is the same for coal, oil or gas. The principle of pre-combustion capture for power plants can be divided into 5 main parts, namely:

- Syngas Island
- CO2 Separation
- CO2 Compression
- Power Island
- Oxygen Island

The Pre-combustion Capture Scheme can be seen in Figure 1.

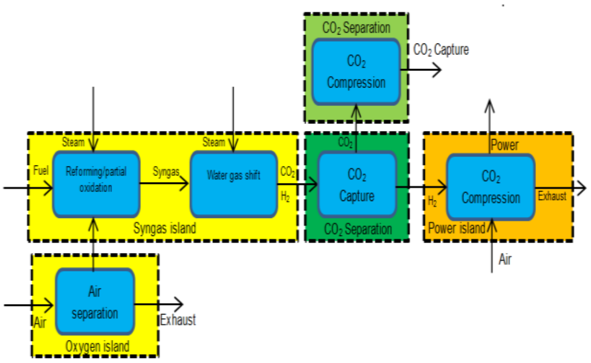


Fig. 1: Pre-combustion Capture Scheme in Power Plants

There has been an increase in efficiency in Pre-combustion, which has arisen from developments in the Natural Gas Combined Cycle (NGCC) or Integrated Gasification Combined Cycle (IGCC) for higher turbine gas efficiency.

B. Coal Clean Technology

a) Fluidized Bed Combustion Technology
FBC technology is divided into two types, namely Atmospheric Fluidized Bed Combustion (AFBC) and Pressurized Fluidized Bed Combustion (PFBC). Using PFBC technology, the coal that will be used in the combustion process is first ground or crushed until it has a size of 6-20 mm. Coal will be injected through the hole located above the air distributor. Along with the process of adding coal, crushed limestone is also added for the desulfurization stage. The combustion process in the boiler takes place in the temperature range of approximately 800 °C. A sufficiently low temperature can reduce the resulting NOx emissions. The use of PFBC technology can reduce SO2 emissions up to 90-95% and NOx emissions can be reduced up to 70-80%. Figure 2 shows a schematic of the PFBC process.

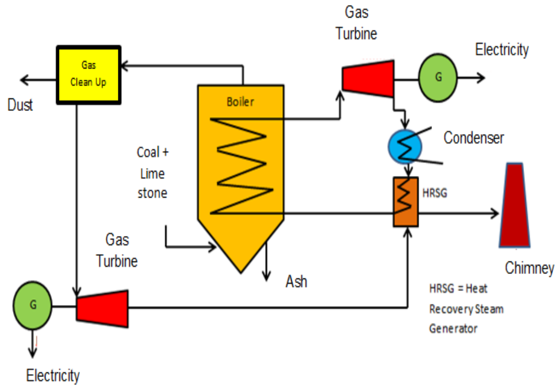


Fig. 2: PFBC Technology Scheme

The gas produced in the combustion process has very high and clean pressure, this pressure can be used to drive a gas turbine. The use of a combination of combustion steam and steam from the HRSG (Heat Recovery Steam Generator) to drive a steam turbine will result in a double cycle which can increase the overall efficiency by around 40-44% [14].

b) Coal Gasification Technology
Gasification technology is a technology that aims to improve coal combustion methods. Coal will be changed from its original solid form to gaseous form, this change can increase efficiency. The gas obtained in the gasification process will be used to drive a gas turbine. The exhaust gas from the gas turbine which is still hot enough will be used by HRSG to drive other gas turbines. This combination is called IGCC (Integrated Gasification Combined Cycle). The schematic of the Gasification process is shown in Figure 3.

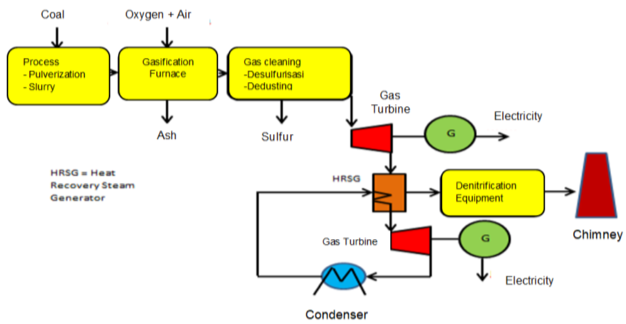


Fig. 3: IGCC Technology Scheme

The gasification process occurs at an early stage using very high temperatures around 1400-1500°C. The ash generated from the combustion residue will melt. The gas produced during the Gasification process is cleaned by Electrostatic Precipitator (ESP) and Desulfurization before being supplied to the gas turbine. After the gas is clean from impurities, it is supplied to a conventional gas turbine to

ISSN No:-2456-2165

generate electricity and exhaust gas in the form of heat to be used to boil water so that steam is produced, which is used for other gas turbines that produce electricity.

The IGCC process has an efficiency of 43-45% and has several advantages, namely, it can increase heat efficiency by up to 50% so that it can save fuel supply and reduce SOX and NOx emissions by around 95-99% and 40-95%. [14].

c) Magneto Hydro Dynamics (MHD) Technology
MHD technology works by using the Faraday effect induction law, where a strong DC electric current (Direct Current) will be generated if the conductor moves through a magnetic field. Coal will be burned to a temperature of 2630°C. At this temperature, potassium hydraulic oil will undergo ionization to change form into a gas which is used as a gas conductor, to pass through a magnetic field and produce a direct current. The inverter functions as a voltage converter from DC to AC. The schematic of the MHD process is shown in Figure 4. The exhaust gas produced during the MHD process can be utilized to produce steam through the assistance of HRSG. The steam obtained will be used to turn a turbine and generate electrical energy from the turbine. By using these two cycles, an efficiency level of 55-60% will be obtained. [14].

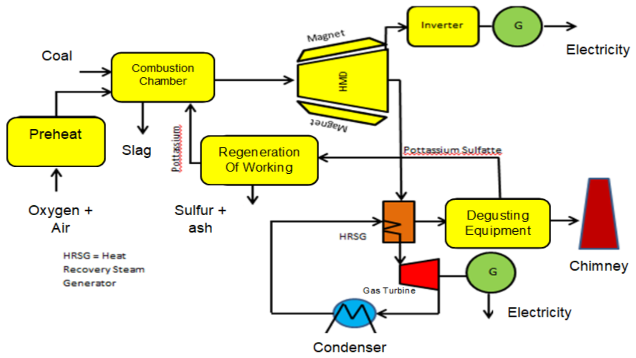


Fig. 4: MHD Technology Scheme

The reduction of SO2 (Sulphuric Dioxide) emissions will occur naturally in the MHD process. Potassium which is used as a working substance will react with the sulfur contained in the coal and will form a potassium condensation solid. This liquid will then be separated from the sulphur or sulphur which is then injected back into the Combustion Space or combustion chamber. The NOx reduction stage is carried out in 2 processes, namely, the first stage will be carried out in the combustion chamber area and the second stage will be carried out on the HRSG. This means that emissions will be reduced under the conventional ESP tools available. The reduction in CO2 emissions continues to decline due to the increasing inefficiency.

d) IGCC and Fuel Cell Combination Technology
IGCC technology can be combined with a Fuel Cell base. A fuel cell is a device that directly converts chemical energy into electrical energy or can be said as a device that produces electricity by combining fuel and oxygen. Developed worldwide such as Alkaline Fuel Cell (AFC), Polymer Electrolyte Membrane Fuel Cell (PEMFC), Solid Oxide Fuel Cell (SOFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC) and Direct Methanol Fuel Cell (DMFC).

Currently, the technology developed to obtain high temperatures is MCFC and SOFC. This configuration will produce three combined or hybrid power plants as shown in Figure 5. The temperature used for FMCFC is approximately 650°C and the temperature used for SOFC operates at a temperature of 1000°C. The overall efficiency rate of this system is about 50-55% [14].

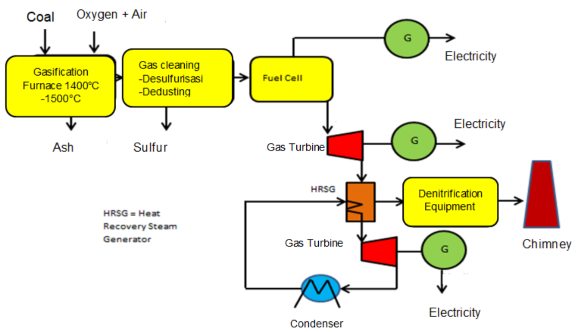


Fig. 5: IGCC and Fuel Cell Combination Technology

C. *Post-Combustion Technology*

This process uses a system that captures CO2 from exhaust gases from burning fossil fuels. In modern power generation processes, pulverized coal is mixed with air and burned in a furnace or boiler. The heat generated in the combustion process is to drive the turbine generator. The hot gas coming out of the boiler consists of nitrogen plus a concentration of water vapour and CO2. Additional products during the coal combustion process include sulphur dioxide, nitrogen dioxide and fly ash. Emissions can potentially be reduced by utilizing Desulfurization technology, Electrostatic Precipitator (Dust Filter), Denitrification and CO2 gas separator. In some additional cases to remove additional pollutants, especially SO2, it is necessary to have a fairly clean gas flow from the CO2 capture process. The schematic of Post-Combustion CO2 capture at the power plant is shown in Figure 6.

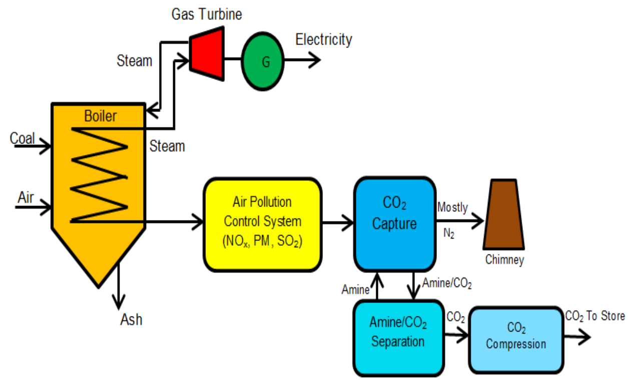


Fig. 6: Schematic of Post-Combustion CO2 capture in power plants

A. Denitrification Technology

- Denitrification Technology strives to reduce NO_x emissions. Its use is through updating the boiler system or installing a denitrification system found in the exhaust boiler that utilizes a two-stage combustion process.
- Boilers that utilize low NOx combustion devices.
- Boilers with the use of an exhaust gas circulation system.
- Boilers that use denitrification equipment in the combustion chamber.

The boiler has the potential to be modified so that it becomes:

Denitrification can be achieved by injecting ammonia into the denitrification, and the ammonia is reacted with NO_x gas contained in the exhaust gas using a catalyst, this aims to reduce NO_x emissions by 80-90%. This denitrification technology is often referred to as Selective Catalytic Reduction (SCR) [14].

B. Desdusting Technology

The application of dedusting technology is used to reduce particles in the form of dust. The dust collection equipment used is an Electrostatic Precipitator (ESP), this equipment is made by placing the electrodes on the exhaust. When the potential difference is 40-60 kV DC, the magnetic field will produce electrodes. Dust particles that cross the ionized magnetic field and mix with the electrodes will produce dust particles that collect on the collector plate and then vibrate the collector plate to remove or drop the accumulated dust. Due to ESP efficiency, the very large can be removed up to 99.9% [14].

C. Desulfurization Technology

Reducing SO_2 emissions can be done with Desulfurization technology. This technology is generally referred to as Flue gas desulfurization (FGD). There are two types of FGD, namely wet FGD and dry FGD. Wet FGD by mixing water and lime then sprayed into the flue gas. This method can reduce SO_2 emissions by up to 70-95% [14]. This wet FGD also produces a gypsum by-product in the form of a liquid.

The use of dry FGD can be done by mixing water and limestone which is then injected into the combustion chamber. This method will be able to reduce emission levels from SO2 up to 70-79%, and the FGD process also produces gypsum mixed with other materials.

D. Oxy-Combustion System

The Oxy-Combustion system was developed as an alternative to Post-Combustion where the partial pressure of CO_2 will be treated by performing a separation process. This separation is done to avoid mixing the exhaust gas with nitrogen in the outside air. The combustion process requires up to 97% pure oxygen and small amounts of nitrogen and argon. This combustion process produces residual combustion which is only concentrated in CO_2, water vapour and small amounts of pollutants such as sulphur dioxide (SO_2) and nitrogen oxides (NO_x). Water vapour can be removed by cooling and compressing the exhaust gases. The removal of these additional pollutants leaves a near-pure CO_2 that can be sent to storage.

The development of Oxy-Combustion is to avoid the need for CO2 in the Post-Combustion process which requires expensive costs in the CO2 capture system. However, this requires an Air Separation Unit (ASU) to produce the relatively pure oxygen needed for the combustion process. Approximately three times more oxygen is required for the Oxyfuel system than for systems using the Integrated Gasification Combined Cycle (IGCC) with Post-Combustion CO2 capture of the same size [11].

In this process, the main thing is that the fuel is mixed with oxygen, as well as CO2 and steam from the exhaust gas recycling which is used to moderate the combustion temperature to the same level as in the Air-Fired Unit. When combustion occurs there is no effective nitrogen, the exhaust gas consists of CO2 and water vapour and impurities such as NOx and SOx. The composition of the CO2 stream originating from Oxy-Fuel combustion has been studied by Liu and Shao. They found that N2 or Ar in O2 concentrations usually varied from 1-6% and 3-5% for each of these elements, and it depended on the pure O2 produced by the Air Separation Unit (ASU) and its equivalence ratio. The vapour concentration in the exhaust gases is in the range of 10-40% depending on the nature of the fuel and the flow of the exhaust gases [5]. Schematic of the Oxy – Combustion system as shown in Figure 7.

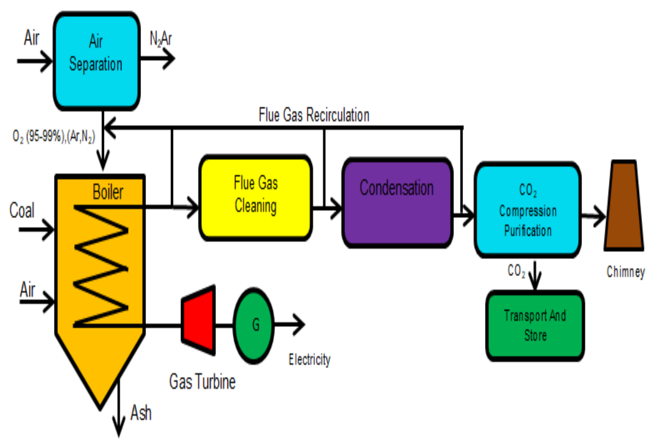


Fig. 7: Schematic of Oxy – Combustion Process

III. CURRENT AND FUTURE CONDITIONS

The Secretariat General of the Energy Council 2019 has calculated the energy supply and energy demand in Indonesia. The analysis uses the calculation of the Long-range Energy Alternatives Planning System (LEAP) model and the calculation of the power supply with the Balmoral model. The use of Business as Usual (BaU) scenarios, sustainable development (PB), and low-carbon scenarios for the 2019-2050 energy supply and demand forecasts. The three scenarios assume a gross domestic product (GDP) growth rate of 5.6% and a population growth rate of 0.7% [12].

The need for electrical energy is increasing day by day compared to other energies. It is estimated that the demand for electrical energy will reach 2,030 kWh/capita (BaU), 1,892 kWh/capita (PB) and 1,834 kWh/capita (RK) in 2025. If calculated until 2050, the demand for electrical energy will reach 6,723 kWh/capita (BaU), 5,824 kWh/capita (PB) and 4,935 kWh/capita (RK). Demand increasing nine times since 2018, a strategy is needed to meet this increase. The strategy is to increase electricity production by 2,562 TWh (BaU), 2,167 TWh (PB), and 1,838 TWh (RK) in 2050, with transmission and distribution losses of 10%. Electricity production at coal-fired power plants will continue to be the number one candidate in Indonesia.

Total power generation has decreased from 57% in 2018 to 41% (BaU), 39% (PB), 32% (RK) in 2050. This is due to an increase in electricity production generated from NRE plants which increased by 27% (BaU), 28% (PB) and 63% (RK) in 2050, this is an increase from 12.4% in 2018. The selection of the type of generator is based on the principle of cheap electricity (least cost). Minimum supply costs are achieved by minimizing the "Net Present Value" of investment costs, fuel costs, operating and maintenance costs. Scenario (BaU) for power generation capacity in 2050 will reach 552.5 GW with 258.8 GW each coming from NRE, 152.5 GW from coal and 141 GW from gas, and the rest coming from oil plants. [6].

IV. CONCLUSION

The need for electrical energy is increasing day by day along with the development of the industrial revolution. Electricity demand is projected to increase almost 9 times by 2050. To meet this demand, the Indonesian government must provide power plants to meet consumer needs. Power plants that can be developed in Indonesia are power plants with environmentally friendly technology. This is because Indonesia has signed the Paris Agreement where the agreement discusses climate change faced by all citizens of the world. The use of coal in very large quantities will of course lead to increased emission pollution such as SO2, NOx, and CO2 particles. Coal generator technology that can be developed based on clean coal technology (Clean Coal Technologies), remains the main choice because the availability of Indonesia's coal reserves is still very large, amounting to 38.84 billion tons.

Various kinds or types of clean coal generation technology that are environmentally friendly are still being developed to obtain more efficient and environmentally friendly methods, especially the use of coal for the power generation process. Coal plants with Higher Efficiency And Low Emission (HELE) are the keys to Clean Coal Technologies (CCT). The application of several clean coal technologies or so-called Clean Coal Technologies must be classified according to the level of the energy production process, especially during the generation of electrical energy, which consists of Pre-Combustion and Post-Combustion technologies. Because the construction of PLTU is not only seen from the technology side, it must be seen from the economic side of the price. The government must also implement good governance by implementing transparency and involving all interested parties in the planning, implementation, monitoring and assessment of development mechanisms. The determination of the price of electricity for coal-fired power plants must be open to avoid excess prices that cause coal-fired power plants to be threatened as assets that are not used after 10-15 years.

ACKNOWLEDGMENT

This work is funded and supported by the Defense University of the Republic of Indonesia, the Faculty of Defense Management, Energy Security Study Program.

REFERENCES

[1.] Gazzani, M., Macchi, E., & Manzolini, G. (2012). CO2 capture in natural gas combined cycle with SEWGS. Part A:. International Journal of Greenhouse Gas Control, 493-501.

[2.] Herdiyan. (2021, Januari 6). Teknologi Maju Dukung PLTU Ramah Lingkungan. Retrieved Desember 9, 2021, from https://ekonomi.bisnis.com/: https://ekonomi.bisnis.com/read/20210109/44/1341405/teknologi-maju-dukung-pltu-ramah-lingkungan

[3.] Indonesia, C. (2021, Oktober 17). Konsumsi Listrik Capai 187,78 TWh per September 2021. Retrieved Maret 8, 2022, from cnnindonesia: https://www.cnnindonesia.com/ekonomi/20211017103219-85-708832/konsumsi-listrik-capai-18778-twh-per-september-2021

[4.] Jansen, D., Gazzani, M., Manzolini, G., Dijk, E. V., & Carbo, M. (2015). Pre-combustion CO2 capture. Greenhouse Gas Control, 167-187.

[5.] Liu, H., & Shao, Y. (2010). Predictions of the impurities in the CO2 stream of an oxy-coal combustion plant. Applied Energy, 3162-3170.

[6.] NASIONAL, S. J. (2019). Outlook Energi Indonesia (OEI) 2019. Jakarta: SEKRETARIAT JENDERAL DEWAN ENERGI NASIONAL.

[7.] Pribadi, A. (2021, 7 27). Cadangan Batubara Masih 38,84 Miliar Ton, Teknologi Bersih Pengelolaannya Terus Didorong. Retrieved 11 22, 2021, from https://www.esdm.go.id/: https://www.esdm.go.id/id/media-center/arsip-berita/cadangan-batubara-masih-3884-miliar-ton-teknologi-bersih-pengelolaannya-terus-didorong

[8.] Pribadi, A. (2021, 10 5). HBA Oktober Naik Lagi, Tembus USD161,63 per Ton. Retrieved 11 23, 2021, from www.esdm.go.id: https://www.esdm.go.id/id/media-center/arsip-berita/hba-oktober-naik-lagi-tembus-usd16163-per-ton

[9.] Pribadi, A. (2022, Januari 12). Capaian Kinerja Tahun 2021 Dan Program Kerja 2022 Sektor ESDM. Retrieved Maret 8, 2022, from esdm: https://www.esdm.go.id/id/media-center/arsip-berita/capaian-kinerja-tahun-2021-dan-program-kerja-2022-sektor-esdm

[10.] RI, K. E. (2022). Capaian kinerja Sektor ESDM Tahun 2021 dan Rencana 2022. Jakarta: KEMENTERIAN ENERGI DAN SUMBER DAYA MINERAL RI.

[11.] Rubin, E., Mantripragada, H., Marks, A., Versteeg, P., & Kitchin, J. (2012). The Outlook For Improved

Carbon Capture Technology. Progress In Energy And Combustion Science, 1-42.
[12.] Siswanto, D. (2019). Outlook Energi Indonesia 2019. Jakarta: Sekretariat Jenderal Dewan Energi.
[13.] Suarna, E. (2011). Perkembangan Teknologi Batubara Bersih Berwawasan Lingkungan. Teknologi Lingkungan, 25-34.
[14.] Sugiyono, A. (2000). PROSPEK PENGGUNAAN TEKNOLOGI BERSIH UNTUK PEMBANGKIT LISTRIK DENGAN BAHAN BAKAR BATUBARA DI INDONESIA. Jurnal Teknologi Lingkungan, 90-95.
[15.] Syahni, D. (2021, November 13). Menguji Keseriusan Indonesia Lepas Energi Batubara Beralih ke Terbarukan. Retrieved 12 8, 2021, from https://www.mongabay.co.id/: https://www.mongabay.co.id/2021/11/13/menguji-keseriusan-indonesia-lepas-energi-batubara-beralih-ke-terbarukan/
[16.] Zhao, G., & Chen, S. (2015). Greenhouse gas emissions reduction in China by cleaner coal technology towards 2020. Energy Strategy Reviews, 63-70.