Carbon Dioxide Capture and Storage in Coal Fired Power Plants: A Case of Belchatow Power Plant in Poland

Paul Ukpaayedo Sukpe

Abstract— **Over the last decades, the world's energy has been growing, yet fossil fuels are limited. Though renewable energies are becoming more prevalent, they are still a long way from been commonplace worldwide. The use of fossil fuels energy resources such as carbon dioxide has triggered global warming and climate change. With the world's efforts to tackle global warming and climate change, the negative effects and stake is indeed worrying. This has urged the need for measures that are aimed at minimizing the effects of using the above-mentioned fossil fuels or energy resources, especially carbon dioxide. The electricity produced from fossil fuel power plants especially coal-fired power plants are challenged through the growing concerns of the so-called greenhouse gases such as carbon dioxide. With reports indicating that coal-fired power plants emit about 2 billions tons of carbon dioxide annually, it means that carbon emissions contribute largely to climate change problems. This paper looks at development trends that is applied to review carbon dioxide capture and storage (CCS) in coal-fired power plants using the Belchatow Power Plant in Poland as a case study. The paper first provides an over of the current research and continued progress in CCS technological developments. CCS could avoid CO_2 being released into the atmosphere. In this study, we discuss the processes of CCS, how these processes are applied at the Belchatow Power Plant, electricity generation in Poland and the Belchatow Power Plant. We conclude that, for the effective operation and implementation of the CCS rules, the company should strictly follow the rules/ regulations set out by the national government and related European regulations.**

Index Terms— **carbon capture and storage, coal-fired power plants, energy, fossil fuels, greenhouse gases.**

I. INTRODUCTION

The rapid economic growth has caused growing energy demand that led to increased utilization of fossil fuels, like coal, oil and natural gas [1]. Consequently, the use of fossil fuels energy resources, especially carbon dioxide has triggered global warming and climate change. Based on the world efforts to address global warming and climate change, the negative effects and stakes of both are indeed alarming. This has urged the need for measures that are aimed at minimizing the effects of using the above-mentioned fossil fuels or energy resources, especially carbon dioxide.

According to [2], the electricity produced from fossil fuel power plants will be challenged through the growing concerns of the so-called greenhouse gases (GHG), such as carbon dioxide. This means that carbon emissions contribute to the climate change problems. Reports indicated that coal-powered plants have annually emitted 2 billion tons of CO_2 or about two-thirds of the US power sector. In a span of 23 years (2007-2030), the present coal-fired power plants are expected to emit more than 90% of CO_2.

Because of such condition, measures to address the CO_2 emissions were devised. Reference [1] noted that these measures seek or aspire to accomplish the following:

- Improve energy efficiency and promote energy conservation;
- Increase the use of low carbon fuels, which includes natural gas, hydrogen or nuclear power;
- Deploy renewable energy, like solar, wind, hydropower and bioenergy;
- Apply geo-engineering approaches such as afforestation and reforestation; and
- CO_2 capture and storage (CCS).

Any of these measures, when adopted, is still unlikely to meet the Intergovernmental Panel on Climate Change (IPCC) goal of CO_2 reduction. This suggests a need to create a complimentary portfolio of CO_2 emission reduction strategies. Apparently, the CCS has the ability to reduce CO_2 emissions from 85% to 90% from huge emission sources, such as power production utilities and energy intensive emitters [1].

Because of such capacity, this report is mainly focused on the CO_2 capture and storage (CCS) as a CO_2 emission reduction strategy. A discussion will be provided on the selection of the CCS, along with the basic descriptions of its essential components, in order to provide comprehensive view on what the technology is all about. These discussions will then be associated with the plan for implementing such strategy to Poland's Belchatow Power Plant as a case study.

II. CO2 CAPTURE AND STORAGE (CCS)

CCS can be defined as an integrated suite of technologies that can acquire up to 90% of CO_2 emissions that are generated from using fossil fuels in electricity production and industrial processes. CCS as well intends to prevent carbon dioxide from entering the atmosphere. CCS is also tagged as the key for reducing global CO_2 emissions from coal, natural gas and even industrial sources [3].

Using the CCS with renewable mass is said to be one of the few carbon abatement technologies, which can be utilized in a so-called "carbon-negative mode" [4]. This means that CO_2 is taken out of the atmosphere. Thus, discussing climate change effectively requires reduction of CO_2 emissions. To best understand the CCS, the three parts of the chain should be

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discussed-capturing the carbon dioxide, transporting and securely storing the carbon dioxide emissions in underground depleted oil and gas fields or deep saline aquifer formations.

A. *Processes of CCS*

This section will present the different processes of CCS, which will aid in further understanding its importance in the reduction of carbon dioxide. As mentioned, these processes include the following:

1. Capturing the carbon dioxide

This part permits the separation of carbon dioxide from gases generated in electricity production and industrial processes by one of the three methods—the pre-combustion capture, post-combustion capture, and oxyfuel combustion [4]. It is apparently essential to discuss the three methods of capturing carbon dioxide in order to understand the said process.

The *post-combustion capture* or flue gas scrubbing is recently hailed as the most developed and popular technique used in the industry of capturing CO_2, from the exhaust gases fossil fuel combustion [5]. The post-combustion technologies are often preferred for "retrofitting existing power plants" [1]. According to [6], post-combustion capture allows the combustion procedures to be secured relatively unaltered or unchanged. Coal is said to be burnt in a conventional combustion chamber and exhaust gases will pass through a particle removal chamber. This chamber separates the ashes from the smoke particles. A flue gas will be then transferred into a CO_2 absorption unit, after the sulphur removal stage. A solvent will absorb the carbon dioxide. The figure below illustrates the post-combustion capture process.

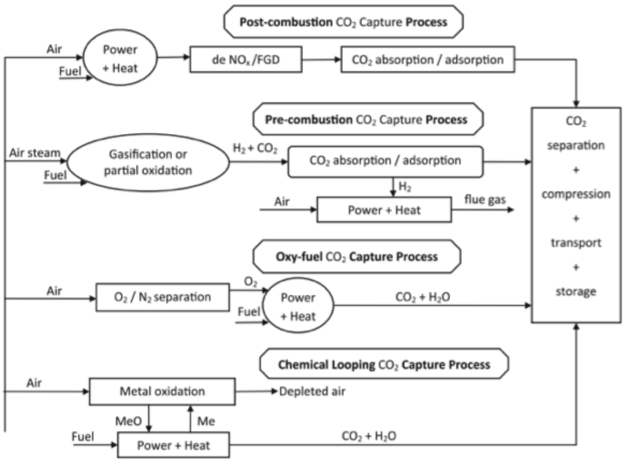

Fig. 1 CO_2 Capture technologies [1]

In addition, [7] underscored that the most widely used capture technology is the chemical absorption process, using amines (monoethanolamine (MEA)), which has been available for industrial applications. MEA CO_2 carbon capture process has been cited as the most proven and tested process. "The basic design allows exhaust gases to pass through an absorber where the MEA interacts with the carbon dioxide and absorbs it" [7]. The CO_2-rich MEA will then be pumped to a stripper called regenerator, which utilizes steam to separate carbon dioxide from the MEA. Water is then removed from the resulting CO_2 through compression while regenerated MEA is purged of any contaminants. This will then be recirculated back to the absorber. The said process can be improved in order to eradicate 90% to 95% of carbon dioxide from the flue gas.

The second capture process is called *pre-combustion process.* This process utilizes a process where coal is relatively converted into clean gas, which is known as syngas [8]. The syngas is primarily composed of hydrogen (H_2) and carbon monoxide (CO). Reference [6] underscored that coal is mainly composed of carbon with some hydrogen, sulphur and varied impurities. In order to extract oxygen from air, an air separation unit (ASU) is used. The extracted element will then be added to the heated Pulverized Coal (PC), which means that coal is pulverized to the consistency of a powder, in order to produce syngas. In removing the sulphur and particulates of the gas, filters and scrubbing units are utilized, before they pass through a shift reactor.

The CO_2-free gas will then be used in a gas turbine generator in order to produce electricity. This gas is almost wholly made of hydrogen. However, the pre-combustion procedure would need essential amount of additional energy to power the ASU and as well to produce the heat needed for coal gasification [6]. The energy penalty is said to be often from 8% to 12% [9]. This is said to be because of the operation in the ASU and the losses during coal gasification. The image below illustrates the pre-combustion process.

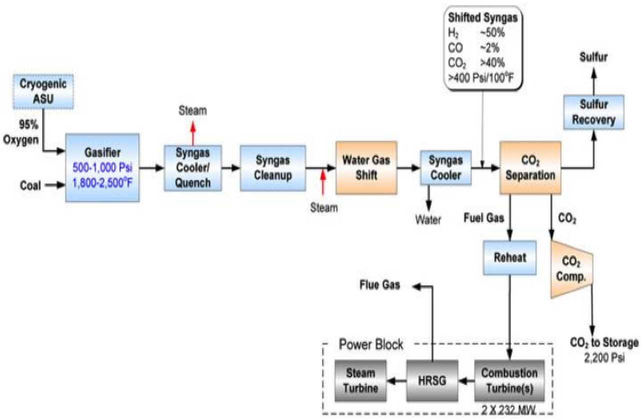

Fig. 2 Process Schematic of Pre-combustion Capture [10]

The last capture process is *oxyfuel combustion.* According to [1], oxygen in oxyfuel combustion is used for combustion, instead of air. This is done in order to exhaust gas that impacts the following separation procedure. Reference [6] stated that oxyfuel combustion has the same techniques with the post-combustion process, particularly when combustion exhaust gases were processed after combustion. It was cited that pulverized coal is pre-treated and the produced fuel in combustion chamber will pass through ASU. Afterwards, coal is combined with CO_2 from the flue gas, to provide a variable CO_2/ O_2 mix. Carbon dioxide is needed for the regulation of the combustion temperature. It also requires fine-tuning to accomplish a peak combustion temperature. The purity of the combustion gas results to minimized exhaust impurities, wherein a bit of filtering should be done before scrubbing CO_2. After scrubbing, small fraction of the generated carbon dioxide will be combined with oxygen to yield oxy-fuel. The figure below best demonstrates the oxy-fuel process.

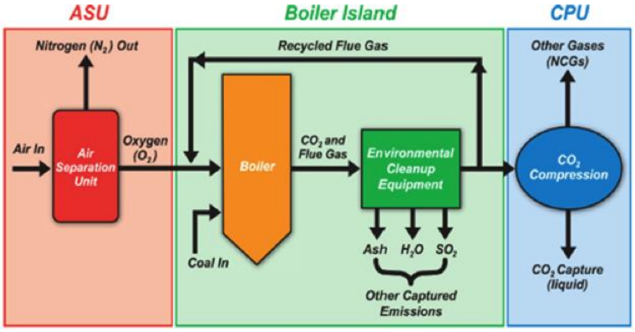

Fig. 3 Oxyfuel combustion [11]

2. Transportation

The second process of CCS is transportation. It was mentioned that this process pertains to the transport of CO_2 to a safe storage. Usually, millions of tonnes of CO_2 are transported yearly, which are utilized for commercial purposes by the pipelines, ships and road tankers. The use of CO_2 is indeed considered as a commodity, which can lead to a portion of it being eternally stored. A noted example is when a concrete is cured by CO_2 or the plastic materials that are based from biomass that utilizes carbon dioxide. Apparently, CO_2 can be converted to biomass, which can be attained through processes like algae farming—given that it uses carbon dioxide as feedstock. Moreover, the harvested algae can be processed into bio-fuels that would replace non-biological carbon sources [3].

Today, CO_2 has been prevalently utilized and consumed in the oil industry for the so-called enhanced oil recovery (EOR) from mature oilfields. CO_2 that is injected into the oilfield can combine with crude oil and can swell. The swelling reduces its viscosity that aids in the maintenance or increase of pressure in the reservoir. The said combination is also said to permit more of the crude oil to flow to the production wells. There are also other instances where CO_2 is insoluble in the oil. In enhanced oil recovery (EOR), injection of CO_2 raises the pressure in the reservoir, which helps in sweeping oil towards the production well. Therefore, CO_2 in EOR can hold positive commercial value and can aid in supporting the use of CCS. EOR can also make a revenue stream for CCS projects, especially when CO_2 captured transforms into an economic resource [3].

The figure below is provided to illustrate an enhanced oil recovery or EOR.

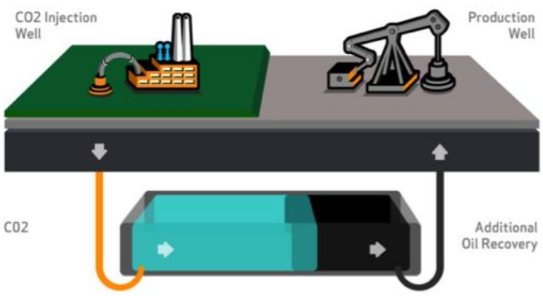

Fig. 4 Enhanced oil recovery or EOR [3]

3. Storage

Storage is where CO_2 is carefully stored in selected geological formations, which are usually located several kilometers below the earth's surface. CO_2 will be pumped deep underground by compressing it through higher pressure, until it becomes a liquid. There are also several different types of trapping mechanisms to consider. These trapping mechanism are based on the physical and chemical features of the rocks and fluids, which can be used for storing CO_2. Every point in the CCS chain or from the production to the storage has been assigned to certain disposal processes and technologies, which are best, understood and possessed outstanding health and safety records [3].

Meanwhile, [1] stated that there are three different common geological formations considered for storing CO_2. These include depleted or nearly depleted oil and gas reservoirs, unmineable coal beds, and saline aquifers. Another feasible option for storage is deep ocean storage, which has been found to be a feasible option. However, deep ocean storage poses environmental threats like ocean acidification and eutrophication, which limits its application. To add, different CO_2 storage in deep oceans can also potentially attain 400 to 10,000 GT for deep saline aquifers, compared with the 920 GT in oil and gas fields and >15 GT in unmineable coal seams (*see [12]*).

Reference [1] as well noted that there are different criteria of consideration for the ability and reliability of CO_2 storage. These are as follows:

- Enhanced oil recovery (EOR) in oil and gas reservoirs;
- Unmineable coal bed storage;
- Storage in saline aquifers;
- Deep ocean storage; and
- In-situ carbonation.

Below is a figure that illustrates the CO_2 storage for coal fired power plants.

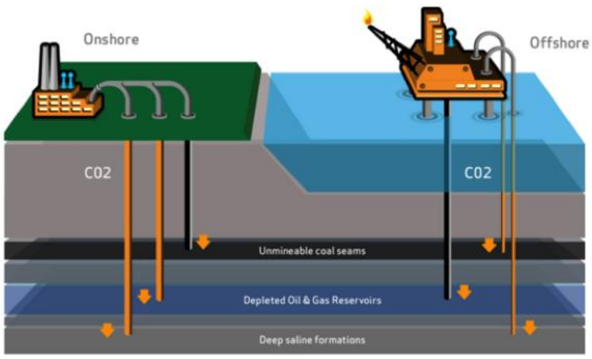

Fig. 5 CCS Storage [3]

III. Case Study: CCS for Belchatow Power Plant

As stated, this report will also look into the application of a CCS in Belchatow Power Plant. The Belchatow Power Plant is located in Poland—a country in Central Europe. The case of Belchatow Power Plant was mainly written and archived by the [14] report. To best understand the whole case, it would be essential to look into some basic information about the Belchatow Power Plant and the industry where it operates. These details will be discussed in the following sections.

A. *Electricity Generation in Poland*

Reference [13] shared that Poland has created worthy and admirable efforts for the development of solid energy policy framework this past few years. Apparently, it was learned that the energy security policy is a high security policy in the country, which implied a need for initiatives that would improve gas supply security. Part of these initiatives and measures are as following:

- Enhancing the gas supply security by establishing an LNG terminal;
- Expanding underground storage capacity; and
- Increasing domestic gas production.

The Polish government planned on the development of electricity and gas cross-border links, which will also contribute to regional security supply. The Polish government as well announced an ambitious project called the nuclear program in 2030, which is also aimed to operate by 2022. The Polish government was also able to accomplish certain energy intensity improvements, along with increasing share of renewables and sturdier focus on energy research and development (R&D) [13].

However, [13] as well noted certain issues to look into Poland's energy sector. These issues refer to the improvement of the region's strategies, such as firmly placing Poland in a low-carbon path, while also improving the energy security. Another concern is for more emphasis on the promotion of competition in the energy policy. The said competition refers to making energy markets more efficient. Apparently, decarbonizing the country's power sector is said to be a huge challenge as it requires huge investments. It was also learned that primary energy in Poland is generated from 55% coal and 92% electricity generation. This implies presence of climate change issues and environmental challenges. At present, Poland is still working on addressing these issues.

In [14] case study, the details about the emissions of CO_2 and other elements were provided. This has served as one of the rationales for considering the CCS for Poland. The said figure is presented below.

		SO_2	NO_x	CO	CO_2
		tonnes			
TOTAL	**2007**	**668 694**	**248 714**	**28 959**	**149 871 528**
	2008	**444 752**	**224 356**	**33 313**	**143 484 841**
Power plants total	**2007**	**530 914**	**197 113**	**22 844**	**118 635 063**
	2008	**344 438**	**177 444**	**28 073**	**115 395 235**
including:					
Lignite	2007	287 566	74 377	10 083	54 784 928
	2008	199 898	71 304	10 721	56 949 340
Hard coal	2007	243 349	122 736	12 761	63 850 135
	2008	144 540	106 141	17 353	58 445 895
CHP total	**2007**	**137 779**	**51 601**	**6 115**	**31 236 464**
	2008	**100 314**	**46 912**	**5 239**	**28 089 605**

Fig. 6 Emission of SO2, NOx, CO and CO2 in Thermal PP and CHPs [14]

On the other hand, the report as well cited PGE Polska Gruppa Energetyczna SA's geographical scope of operations. PGE has been described as the biggest power company in Poland that generates 45% of the total electricity production in the country. Because of these, it became more understandable for EU CO_2Europipe to consider the establishment of a CCS through PGE and with the aid of the Belchatow Power Plant. The said figure indicates the details below.

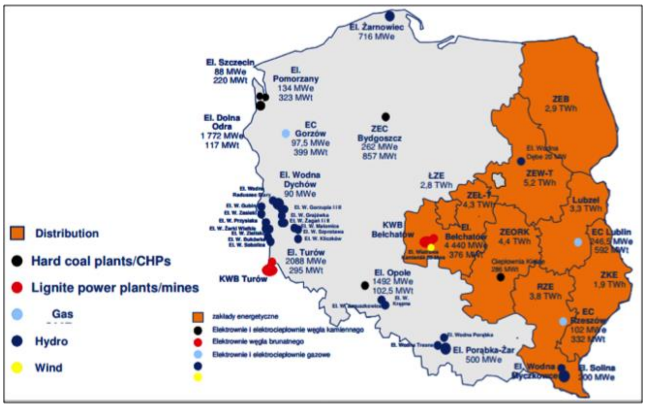

Fig. 7 Main generating assets of the PGE [14]

B. *The Belchatow Power Plant*

The [14] report stressed that PGE GiEK S.A. is the biggest power generating company in the region, wherein it is composed of 12 lignite-fired power units of the capacity of 370 MW. Each of these would contribute to a "total of installed capacity of 4,440 MW in three units of producing thermal power operating in a combined cycle" [14]. Meanwhile, the yearly electric energy output has already reached to 27.8 TWh, while the thermal power output in a year has been more than 2,100,000 GJ (0.6 TWh).

On the other hand, an important profile about the Belchatow Power Plant has been provided by the [15] site, in which it has been described as the biggest lignite-fired power plant in Europe. It was also said to be commissioned in 1988 and is operated by the PGE Elektrownia Belchatow (PGE). At present, the plant holds to about 20% of the Polish power market. On January 2011, PGE has commissioned the 13th unit. This unit has a capacity of 858 MW and has the highest efficiency with 41% and also conforms to the European standards on greenhouse gas emissions. The said generator was commissioned on September 2011.

For the PGE to grow and maintain its lead in the domestic power generation market, certain aspects of the CCS have been suggested by the [14] report. One of these refers to complying with the rules and regulations of the "Strategy for Development of the Generating Power at PGE GiEK S.A." This provision is said to assume the establishment of a new 858 MW power by 2006, while the power units no. 3-12 are still to be exposed to complete upgrading. The development of the power units is said to be established on basic assumptions like extending the operating times of units 1 and 2 until 2016 and units no. 3 to 12 from years 2030 to 2035. Operating parameters is also suggested to be developed and enhanced, in the form of lessening any negative environment protection requirements, based on the EU Directive 2001/80/EC. Also, increase on the present capacity of the Power Plant of up to 4,500 MW has been suggested.

Meanwhile, the basic engineering design and structure for the boiler unit was proposed to be delivered through the ALSTOM Power Boiler Company. This company and RAFAKO S.A. will detail the engineering design for the pressure part and steel structures, which includes material supplies. Both of these companies are said to be experienced in the field and of the same projects, as traced through their participations.

It was also mentioned that the most essential equipment to be installed at the boiler room is the "supercritical steam forced-through-flow tower boiler featuring a pulverized fuel fired furnace" [14]. The boiler is also noted to be provided with "8 fan-type beater pulverizing mills, two air and flue gas fans, burners, bunkers, a rotating and a steam air preheater" " [14]. Other required electrical engineering installations, local measuring systems and auxiliary systems will also be provided. The boiler is also featured with "longitudinal afterburning grate, along with slag trap and system of soot blowers" [14]. This boiler pressure is also said to be structured by design durability of two hundred thousand hours of operation, in compliance with the EN and Din standards, which is equivalent to 25 years of operation.

IV. Conclusions

This report looked into the CO2 capture and storage (CCS) and the different components that cover it. These components were basically the processes involved in CCS, such as capturing the carbon dioxide, transporting and securely storing the carbon dioxide emissions in underground depleted oil and gas fields or deep saline aquifer formations. Indeed, these components are essential to be considered, as manifested in the case study of the Belchatow Power Plant by [14] in Poland.

It was also learned that the whole process of CCS and its application requires careful study of the processes involved and the compliance of certain rules and government legislation. Apparently, the case of Belchatow Power Plant has been moved by environmental issues, along with the need to meet the demands of the people. Therefore, it remains important that further developments in the field of CCS and coal generating plants to carefully assess the abilities of addressing such needs and the strengths and weaknesses of every CCS process (*see* Appendix Section, Figure 8). In this manner, the whole process would be deemed successful.

V. Recommendations

Reference [14] has suggested certain measures and even a plant (*see* Appendix Section, Figure 9) described as the 858 MW unit. The said plant is composed of lignite that is delivered from nearby strip mine, utilizing present belt conveyors that connect Belchatow Power Plant and the mine. The said plant is also said to be comprised of the required features of all the needed systems, such as the basic and auxiliary installations, which are to be provided based on the technical specifications.

In this case, the recommendations to be presented for the Belchatow Power Plant is further surrounded in the aspect of ensuring that the requirements for CCS are met, as guided and established by the national government and the related legislations. Also, the company should ensure the monitoring and evaluation of the plants' operations and the implementation of the CCS rules. Awareness on the stakeholder needs, while further and timely awareness on research and development should be practiced.

VI. Appendix Section

Capture process	Application area	Advantages	Disadvantages
Post-combustion	Coal-fired and gas-fired plants	Technology more mature than other alternatives; can easily retrofit into existing plants;	Low CO_2 concentration affects the capture efficiency;
Pre-combustion	Coal-gasification plants	High CO_2 concentration enhance sorption efficiency; fully developed technology, commercially deployed at the required scale in some industrial sectors; opportunity for retrofit to existing plant;	Temperature associated heat transfer problem and efficiency decay issues associated with the use of hydrogen-rich gas turbine fuel; high parasitic power requirement for sorbent regeneration; inadequate experience due to few gasification plants currently operated in the market; high capital and operating costs for current sorption systems;
Oxyfuel combustion	Coal-fired and gas-fired plants	Very high CO_2 concentration that enhances absorption efficiency; mature air separation technologies available; reduced volume of gas to be treated, hence required smaller boiler and other equipment;	High efficiency drop and energy penalty; cryogenic O_2 production is costly; corrosion problem may arise;
Chemical looping combustion	Coal-gasification plants	CO_2 is the main combustion product, which remains unmixed with N_2, thus avoiding energy intensive air separation;	Process is still under development and inadequate large scale operation experience;

Fig. 8 Strengths and Weaknesses of CCS [1]

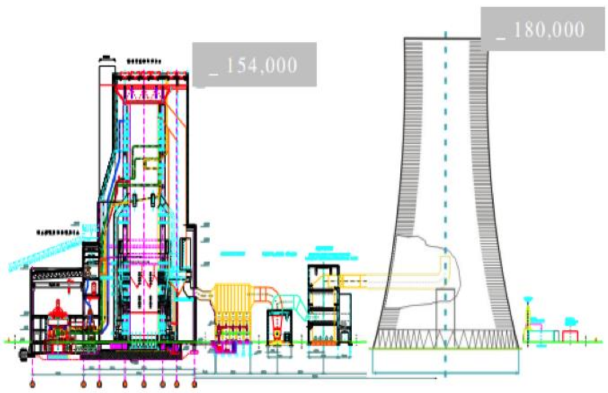

Fig. 9 Summary diagram of the 858 MW power unit

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