

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

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**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 being 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub>.

Because of such condition, measures to address the CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> reduction. This suggests a need to create a complimentary portfolio of CO<sub>2</sub> emission reduction strategies. Apparently, the CCS has the ability to reduce CO<sub>2</sub> 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<sub>2</sub> capture and storage (CCS) as a CO<sub>2</sub> 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. CO<sub>2</sub> CAPTURE AND STORAGE (CCS)

CCS can be defined as an integrated suite of technologies that can acquire up to 90% of CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> is taken out of the atmosphere. Thus, discussing climate change effectively requires reduction of CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> absorption unit, after the sulphur removal stage. A solvent will absorb the carbon dioxide. The figure below illustrates the post-combustion capture 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<sub>2</sub>) 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<sub>2</sub>-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.

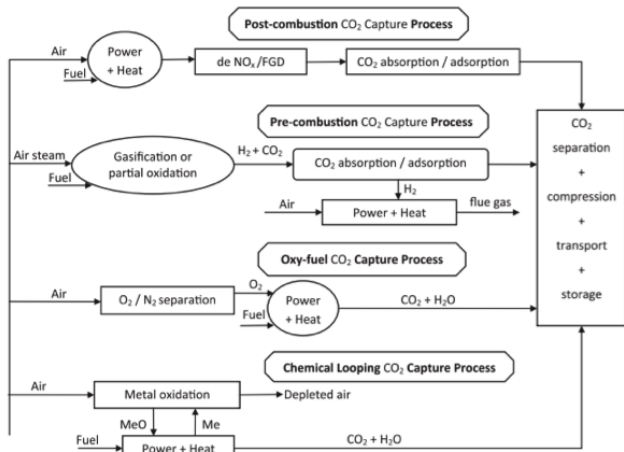


Fig. 1 CO<sub>2</sub> Capture technologies [1]

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<sub>2</sub> 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<sub>2</sub>-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<sub>2</sub> through compression while regenerated MEA is purged of any contaminants. This will then be recirculated back to the absorber. The said process

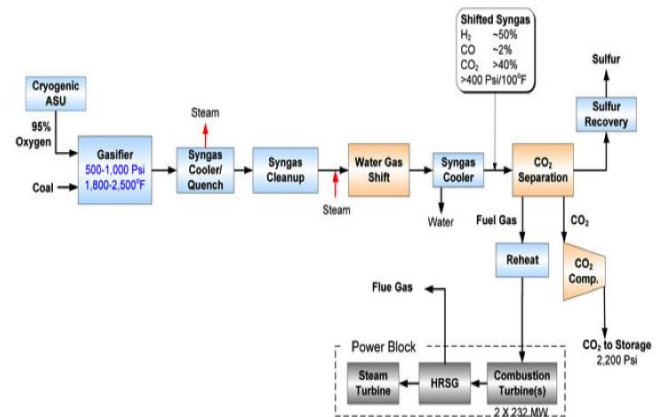


Fig. 2 Process Schematic of Pre-combustion Capture [10]

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<sub>2</sub> from the flue gas, to provide a variable CO<sub>2</sub>/ O<sub>2</sub> 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<sub>2</sub>. 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.

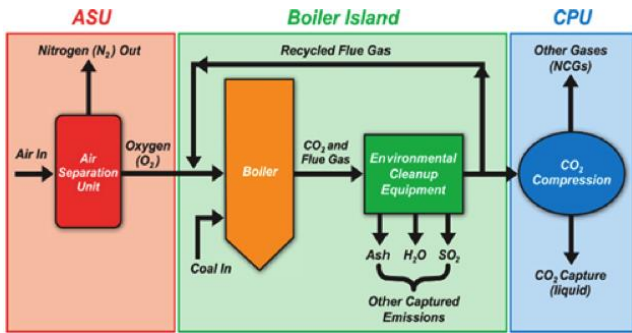


Fig. 3 Oxyfuel combustion [11]

## 2. Transportation

The second process of CCS is transportation. It was mentioned that this process pertains to the transport of CO<sub>2</sub> to a safe storage. Usually, millions of tonnes of CO<sub>2</sub> are transported yearly, which are utilized for commercial purposes by the pipelines, ships and road tankers. The use of CO<sub>2</sub> 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<sub>2</sub> or the plastic materials that are based from biomass that utilizes carbon dioxide. Apparently, CO<sub>2</sub> 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<sub>2</sub> has been prevalently utilized and consumed in the oil industry for the so-called enhanced oil recovery (EOR) from mature oilfields. CO<sub>2</sub> 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<sub>2</sub> is insoluble in the oil. In enhanced oil recovery (EOR), injection of CO<sub>2</sub> raises the pressure in the reservoir, which helps in sweeping oil towards the production well. Therefore, CO<sub>2</sub> 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<sub>2</sub> captured transforms into an economic resource [3].

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

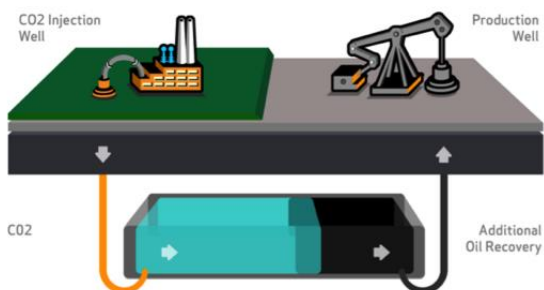


Fig. 4 Enhanced oil recovery or EOR [3]

## 3. Storage

Storage is where CO<sub>2</sub> is carefully stored in selected geological formations, which are usually located several kilometers below the earth's surface. CO<sub>2</sub> 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 mechanisms are based on the physical and chemical features of the rocks and fluids, which can be used for storing CO<sub>2</sub>. 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<sub>2</sub>. 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> storage for coal fired power plants.

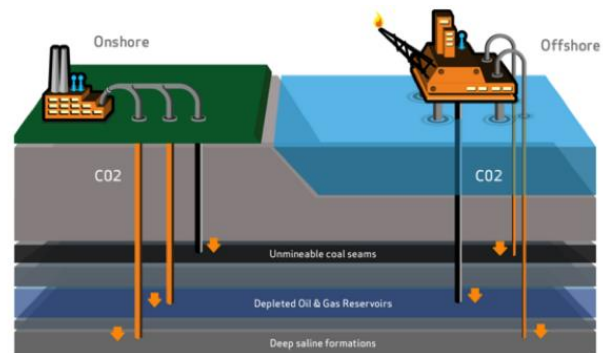


Fig. 5 CCS Storage [3]

## 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



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 CO<sub>2</sub> 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 <sub>2</sub> concentration affects the capture efficiency;
Pre-combustion	Coal-gasification plants	High CO <sub>2</sub> 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 <sub>2</sub> 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; exogenic O <sub>2</sub> production is costly; corrosion problem may arise;
Chemical looping combustion	Coal-gasification plants	CO <sub>2</sub> is the main combustion product, which remains unmixed with N <sub>2</sub> , 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]

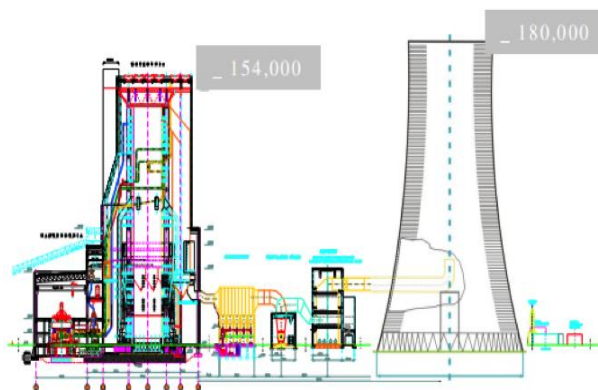


Fig. 9 Summary diagram of the 858 MW power unit

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