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The race to capture carbon creating a sustainable future.

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Abstract: This literature review is the first chapter in a series focused on carbon capture and storage (CCS) techniques, specifically pre-combustion, post-combustion, and oxyfuel combustion. It comprehensively examines their advantages, disadvantages, and associated challenges. Additionally, the study delves into the environmental impacts of CCS. By exploring these key aspects, this review provides a foundational understanding of CCS for researchers, policymakers, and industry professionals, facilitating informed decisions in pursuing effective carbon mitigation strategies and a sustainable future.

keywords — carbon capture, pre-combustion, post-combustion, oxyfuel combustion, environmental impact.

1 INTRODUCTION

This paper studies Carbon Capture and Storage (CCS) as a method to mitigate climate change [1]. Rapid growth in technology and world population resulted in a significant increase in fossil fuel consumption (nearly 90% of world energy demand is highly dependent on fossil products[2]) that is available in limited quantities and has a severe environmental impact[3],[4] which causes global warming and more serious health problems.[5]. Regardless of afford towards renewable energy sources, such as solar energy[6], wind energy[7], and geothermal energy[6], Since the existing CCS technologies are expensive, considerable advancements are required to create CCS technology that is cheap. As a result, the main goal of this inquiry is to analyze CCS technologies and investigate current attempts by the scientific community to develop a novel strategy that can lower the overall cost of this crucial technology. The first step of CCS is carbon dioxide capture, after which biomass or fossil products are produced. The carbon dioxide is then compressed to create a thick fluid that aids in transporting and storing the gas. Pipelines are used to carry the viscous liquid, which is subsequently pumped into an underground storage facility[8]. Since the existing CCS technologies are expensive, considerable advancements are required to create cheap CCS technology. As a result, the main goal of this inquiry is to analyze CCS technologies and investigate current attempts by the scientific community to develop a novel strategy that can lower the overall cost of this crucial technology[9].

2 CARBON CAPTURE TECHNOLOGIES

The combustion process emits a substantial amount of carbon dioxide, which can be added value through manufacturing processes if not directed toward the atmosphere [8] by raising greenhouse gas concentrations [10]. If human activities continue, global warming is likely to reach 1.5 c between 2023 and 2052, According to the 21st Conference of Parties of the United Nations[11]. Therefore, The prime aim of carbon capture and storage technology is to generate a form of carbon dioxide that can be stored [12]. Three main stages are involved in applying carbon capture and storage in power plants. Fig. 1 shows Carbon capture, transportation of the captured carbon dioxide, and carbon dioxide sequestration chain[13]. CO_2 must be compressed into a liquid for pipeline transport; hence, The compression process is also a part of the CCS process [12].

The type of technology determines the state and the purity of gas surrounding CO_2 [14]. Technological concepts to capture carbon dioxides are mainly pre-combustion, post-combustion, and oxyfuel combustion capture [15]. Fig. 2 will be examined in more detail in the section after that.

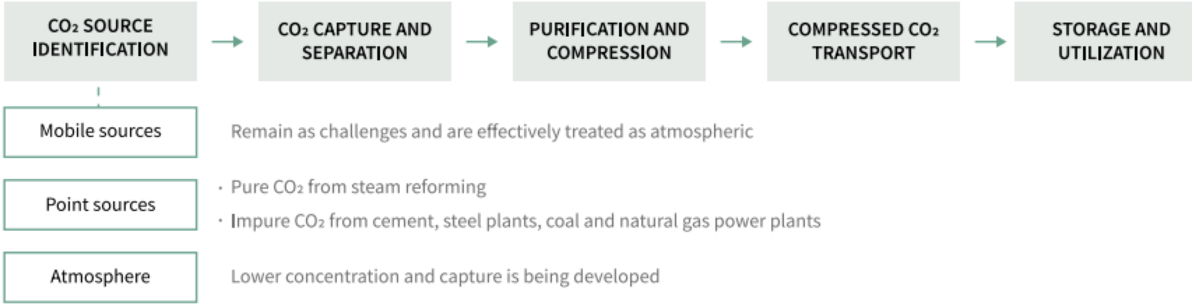

Fig. 1. Carbon flow chain [16]

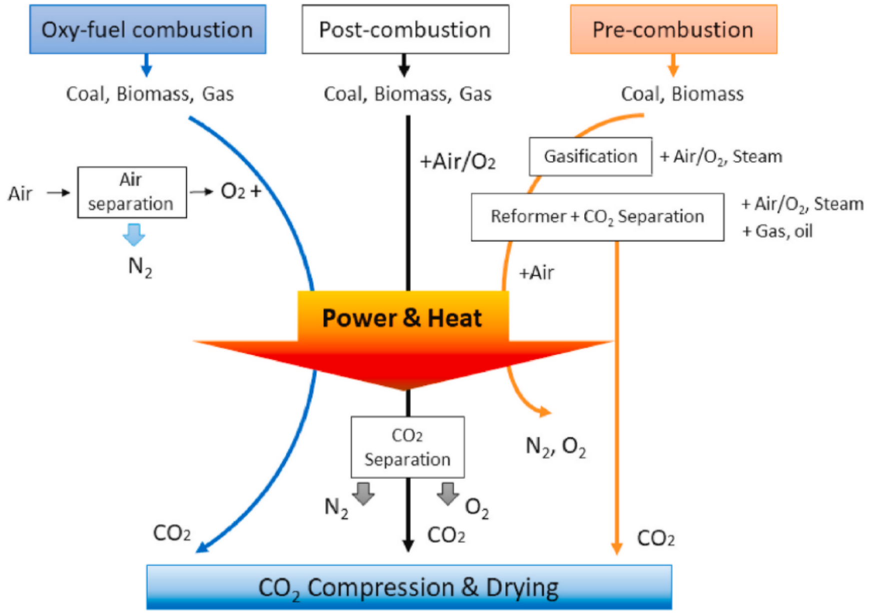

Fig. 2. Varies carbon capture technologies[17]

2.1 Pre-combustion

This technology separates carbon dioxide from fossil fuel before burning [8]. The configuration is illustrated in Fig. 3. Typically, it is applied in (coal, natural gas, and biomass) gasification and natural gas power plants [18],[19].In pre-combustion capture, a fuel is reacted with oxygen, air, and/or steam to produce a fuel gas known as a "synthesis gas" or "fuel gas," which is predominantly comprised of carbon monoxide and hydrogen[20]. The main routes to produce syngas are [21],

01) Steam forming

$$C_xH_y + xH_2O \leftrightarrow xCO + (x+y/2)H_2 \Delta H_{CH4} \tag{1}$$

02) Partial oxidation – when applied to liquid fuel, Gasification – when applied to solid fuels

$$C_xH_y + x/2O_2 \leftrightarrow xCO + (y/2)H_2 \Delta H_{CH4} \tag{2}$$

In a shift converter, CO is reacted with steam to produce CO_2 and additional hydrogen. A further physical or chemical absorption technique is used to extract CO_2[22],[20], then The syngas production is followed by the water-gas shift (WGS) reaction to convert CO to CO_2 and H2 by the addition of steam [21].

03) Water-gearshift :

$$CO + H_2O \leftrightarrow CO_2 + H_2 \Delta H \tag{3}$$

Pre-combustion capture is usually associated with the process stream with higher carbon dioxide concentration (i.e., 15–60% by volume, dry basis) and elevated pressure (i.e., 2–7 MPa) [23]. and a high-temperature range of 200–400 °C [8],[24]. Regularly, the syngas stream after the catalyzed WGS process has been reported to contain 64–73 mol % hydrogen and 20–23 mol% carbon dioxide [24].

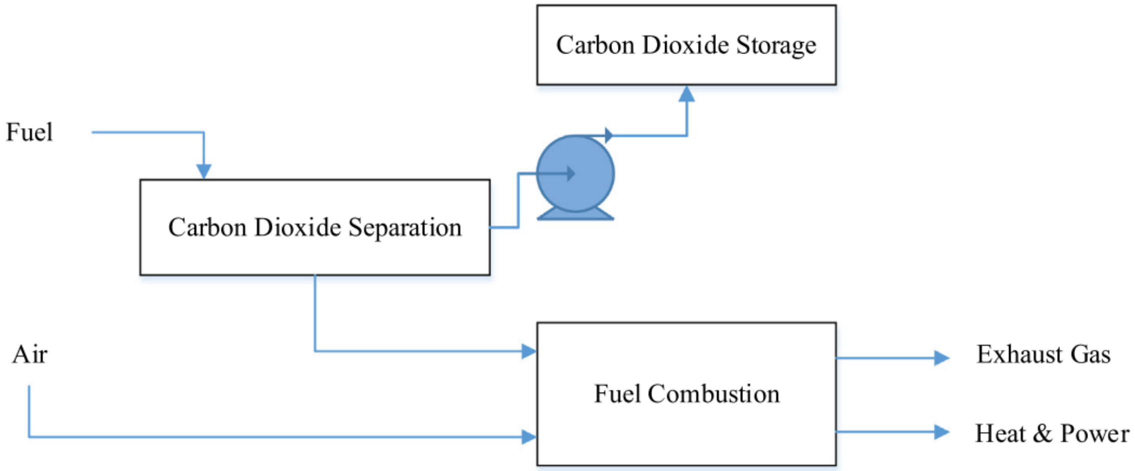

Fig. 3. Diagram of pre-combustion carbon capture system [18]

2.1.1 *Advantages and disadvantages of pre-carbon capture*

Table 1. Advantages of pre-carbon capture ([21],[23],[25],[26],[27]*)*

• Carbon dioxide concentration can be high in the output stream, which makes the capture process less energy-intensive and minimizes capital equipment costs.
• Reduce energy losses.
• Produce high-purity h_2 for chemical and refining uses.
• Co_2 separation steps consume little energy due to the small reaction volume and lower volumetric flow rate at elevated temperatures.
• It can fuel the turbine cycle since syngas are produced at the first step.
• Less water is used compared to post-combustion. • Generate CO_2 under pressure; thus, less energy is required for compression.

Table 2. The disadvantages of pre-carbon capture([23],[25],[28]*)*

• Initial fuel conversion steps are more costly than in post-combustion capture systems.
• Operational cost is high.
• Application mainly to new plants as a few coal gasification plants are in portion. • Syngas have to be dried before CO_2 capture. • Retrofit to existing plants is costly and difficult • For non-gaseous feedstocks, the stream must be cleaned due to impurities.

2.2 *Post-combustion*

The considerable amount of electricity consumed by the world in recent times is obtained from power plants that function through a combustion process[8]. The post-combustion CO_2 capture technique removes CO_2 and other gases from burning fossil fuel resources by physical or chemical adsorption/absorption mechanisms. Its classifications are adsorption, absorption, membrane separation, and chemical reactions [17]. This approach involves separating CO_2 from flue gases from large-scale fossil fuel combustion like boilers, cement kilns, and industrial furnaces[29]. It is An exothermic reaction. Fig. 4 shows post-combustion carbon dioxide capture.

Today, absorption processes (which is confirmed by several research groups, including EPRI (Palo Alto, USA) [17]) using a chemical solvent like amine capture carbon dioxide from many power plants[29]. In evaluating post-combustion CCS, absorption is used in 57% of cases, adsorption in 14% of cases, membranes in 8%, and mineralization or bio-fixation in 21% of cases[17].

The hot flue gas is cooled to temperatures between 40 and 60 °C and then introduced to the absorber, where CO_2 bonds with the chemical solvent. The CO_2-rich solvent is then pumped to a stripper where the solvent is heated for solvent regeneration between 100 and 140 °C, and CO_2 is stripped off[29]—Fig. 5 shows a carbon capture from the absorption process. The fuel type determines the CO_2 content in the flue gas, and a typical CO_2 recovery of 80–90% can be realized in the CC absorption process. Remove nitrogen oxides NOx and sulfur oxides SOx to prevent them from reacting with the solvent; hence, maximizing CC is possible[22],[26].

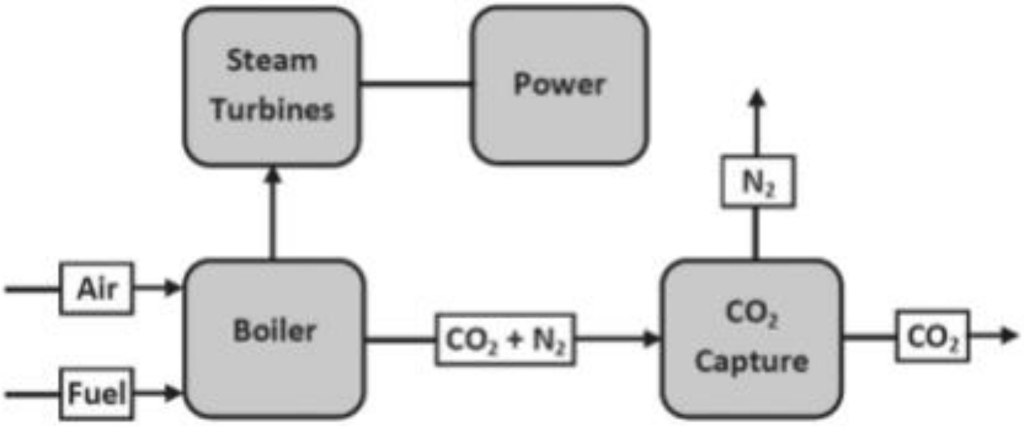

Fig. 4. Post-combustion carbon dioxide capture [30]

Carbon capture models have been implemented for many different industrial applications, such as coal-fired power plants [32, 33], gas-fired power plants [34], the Cement industry [35, 36, 37], and the Aluminium industry [38]. At the same time, parameters have been optimized for post combustion carbon capture process [39, 40, 41, 42, 43, 44].

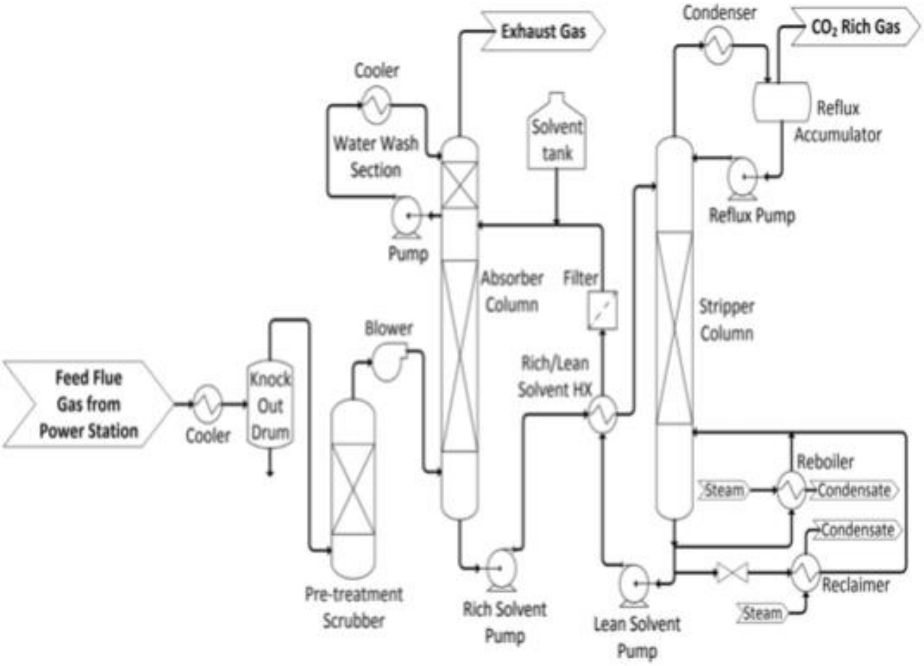

Fig. 5. Carbon capture from the absorption process [31]

2.2.1 *Advantages and disadvantages of post-carbon capture*

Table 3. advantages of post-combustion ([23],[27]*)*

• Applicable to new and existing coal power plant
• Reduce energy penalty since R&D improves sorbent and capture equipment.
• It can increase plant efficiency and reduce emissions.
• Extract pure carbon dioxide for oil recovery, urea production, and the food industry.

Table 4. Disadvantages of post-combustion ([23],[17],[45],[46],[27]*)*

• Water requirement (nearly double per net MWh for water-cooled plants).
• Sorbent needs very pure flue gas to minimize sorbent usage and cost.
• Higher performance volume is required for higher capture levels.
• Current amine technology loses net power output of ~30%.
• Amine-based processes are available on a small scale (not entirely in large plants).
• Corrosion and solvent degradation • Used for the exhaust gas with a low CO_2 concentration (4–14% v/v), which limits the application of this capturing method

2.2.2 *Challenges*

A significant challenge towards CCS design is that a 500 MW fossil fuel-fired power plant emits about 8000 tons/day of CO_2 [7]; hence, considerable scaling is required due to the unavailability of large scale[23]. Developing a compact and flexible capture unit to deal with small industrial emissions, low operating and capital costs, and high efficiency [17]. Finding a next-generation solvent with low regeneration temperatures will significantly reduce corrosion, degradation, and operational costs [17].

2.3 *Oxyfuel combustion*

oxyfuel combustion is becoming an exciting option for CO_2 capture[47] since it can use advanced steam technology, reduce equipment size and cost, and design a zero-emission power plant[35]. Fuel is burned with pure oxygen [48] to produce flue gas with high CO_2 concentrations free from nitrogen and its compounds, such as NO and NO_2 to the production of CO_2 and H_2O [22] since this avoids the need for chemicals or other means of CO_2 separation from the flue gas [49]. Additionally, fly ash is removed from the flue gas stream, leaving only CO_2, water droplets, and pollutants like sulfur dioxide in the flue gas[50]. High pressure in the 20-30 bar range and temperatures between 100 and 300 °C are required for the oxyfuel combustion to respond[51]. The primary units of oxyfuel combustion are [34], as shown in Fig. 6.

- Air Separation Unit (ASU) – oxygen production;
- Boiler or Gas Turbine – combustion of fuel & generation of heat;
- Flue Gas Processing Unit – flue gas cleaning or gas quality control system (GQCS);
- CO_2 Processing Unit (CPU) – final purification of the CO_2 for transport & storage.

The

The fuel combustion efficiency is affected by an air separation unit load, compression of CO_2 and air, working fluid temperature, and turbine cooling load [52].

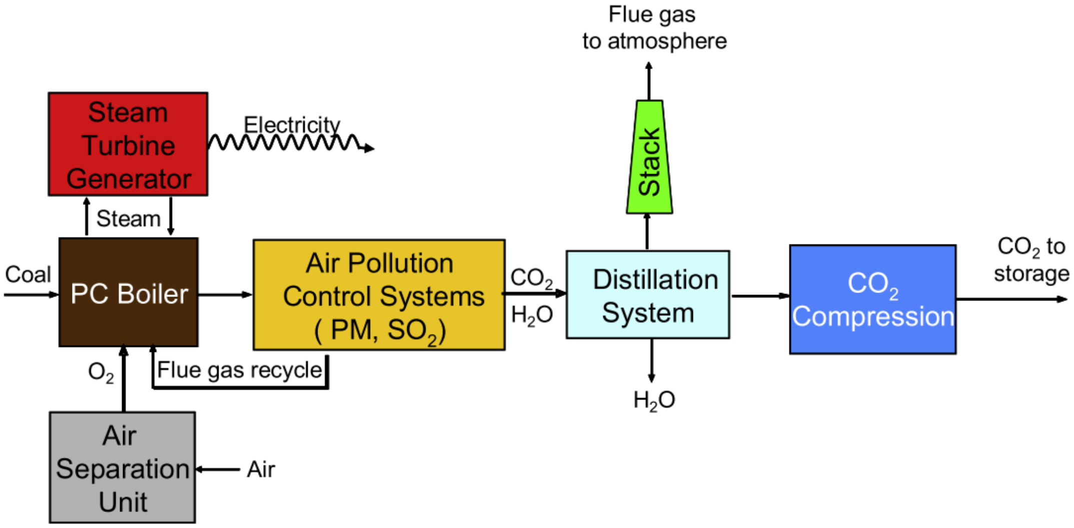

Fig. 6. A simplified version of oxy-combustion in a coal fire powerplant [52]

2.3.1 *Advantages and disadvantages of oxyfuel combustion*

Table 5. Advantages of oxyfuel combustion ([8],[23],[53]*)*

- avoiding a costly post-combustion CO2 collecting system.
- Low emission can be archived as low cost.
- Cost-effective to pre and post-combustion.
- Easier to repower into an existing power plant.
- It can utilize a wide variety of coal.
- No on-site chemicals are required.
- Niragen free combustion

Table 6. disadvantages of oxyfuel combustion ([23],[25],[54],[37]*)*

- corrosion, fouling, potential leaks into the plant, high maintenance cost, and very stringent safety management occurs due to change in ash chemistry in highly concentrated oxygen.
- Oxygen is expensive
- Production's environmental impacts are high because of the energy-intensive air- air-separation processes.
- Air leaks into the system degrade performance.
- Technology must be provided in integrated operations on a large scale and under different operating conditions.
- It is not possible to develop sub-scale oxy-combustion technology at existing power plants.
- Water vapor must be reduced to 50–100 ppm to prevent corrosion.

2.3.2 Challenges

Due to advanced research and development, oxyfuel combustion technologies are developed even though technical and economic challenges must be overcome in system operation and boiler designing [44]. Comprehensive information for boiler designs is in these references [55],[56],[57]. On the other hand, The economic challenge is the high energy cost regarding O_2 production and CO_2 separation[44]. One of the challenges for CLC is its application to solid fuels and ash handling. To operate the CLR system under the high pressure needed to achieve efficiencies equivalent to the state-of-the-art oxyfuel process or post-combustion capture [37].

3 ENVIRONMENTAL IMPACT OF CARBON CAPTURE

Carbon capture is proven that it is an emissions reduction solution by permanently removing CO_2 from the atmosphere. Generally, the benefits of CCS are environmental, economic, and social, with positive and negative impacts, both local and global [58]. As the purpose of CCS technology is to reduce the negative effect of anthropogenic greenhouse gas emissions on the environment, the environmental benefits of CCS must outweigh the potential environmental risks [49]. International evidence shows CCS contributing 17 % of the necessary global emissions reductions in 2050 (from coal, gas, and heavy industry users) and delivering 14% of the cumulative emissions reductions needed between 2015 and 2050 in a 2 Degrees Scenario[60] shown in Fig. 7.

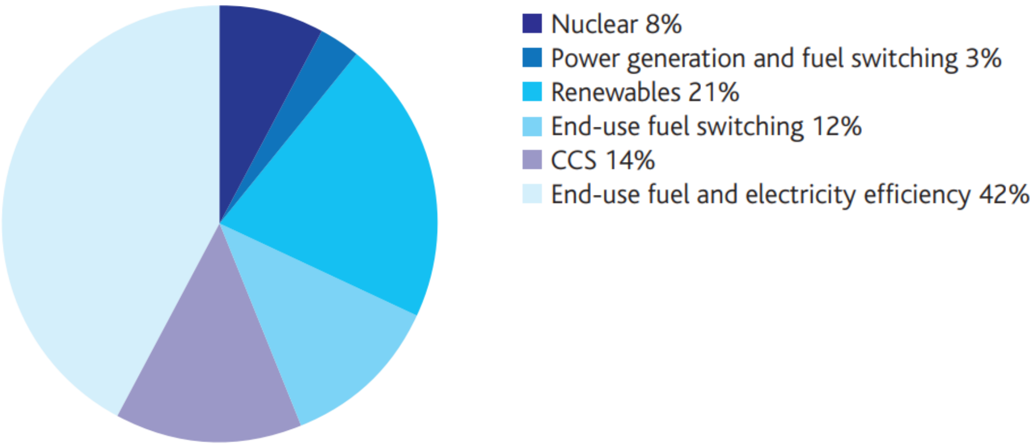

Fig. 7. CCS will contribute 14% of total emission reductions by 2050 in a 2 Degrees Scenario[60]

3.1 *Benefits of carbon capture*

- Help keep average global warming to less than 2 C within this century by climate change mitigation [33].
- Reduce atmospheric CO$_2$ while fossil fuels are continuously used for energy consumption[49].
- Greenhouse gas emissions from electricity production will continue to rise until approximately 2020. Suppose CCS technologies are applied to all new coal and gas-fired electricity generation in combination with efficiency improvement and fuel switching. In that case, the result will be an absolute global reduction in electricity emissions[51].
- Carbon capture is an opportunity for new industrial development, such as hydrogen production and fertilizer production with ccs[48].
- Opportunities for employers

3.2 *Risks of carbon capture*

- Carbon dioxide is part of the atmosphere and is essential to all life forms. It is odorless and non-toxic. However, as it is denser than air, it can harm humans and animals if it accumulates in low-lying areas in high concentrations [49].

Table 7. Environmental impacts are relevant in an EIA for CCS (in the Netherlands)[52].

IMPACT	POWER PLANT
LAND USE	Area (in hectares) occupied by the installation and surrounded regulated zones (e.g., safety zones).
ARCHAEOLOGICAL AND CULTURAL HERITAGE	Destruction of archaeological artifacts in the ground during construction, the demolition of typical geomorphologic occurrences in the landscape or cultural heritage.
BIODIVERSITY	General: destruction, disturbance, and dispersion of habitat during construction, operation, and dismantling.
RAW MATERIALS RESOURCES AND WATER USE	-Use materials (e.g., MEA) for emission reduction (SCR, FGD). -Process and cooling water use.

VISUAL IMPACT	Impact of installation (e.g., stack) considering its surroundings.
ENERGY REQUIREMENT	Total capacity and energy requirement of gross production, net production, and efficiencies of alternatives are required.
GASEOUS EMISSIONS AND IMMISSION	CO_2, NOx, SOx, hydrocarbons, Particulate Matter, Volatile Organic Compounds, and heavy metals.
WASTE MANAGEMENT	Solid waste handling, quality, and quantity of waste flows.
NOISE, LIGHT, AND ODOUR NUISANCE	-Noise zoning. -Light emissions/emissions. -Odour emissions/emissions.
SOIL DISRUPTION	Soil disruption during the construction and dismantling phase.
SOIL CONTAMINATION	Leaching of substances from waste/fuel storage.
SAFETY	Internal/External safety for area: -Ammonia storage (SCR). -Solvent storage (amines/selector).
GROUNDWATER AND SURFACE WATER DISTURBANCE/CONTAMINATION	Cooling water discharge: water withdrawal, water heating, and mix zone effects. -Contaminants: emissions and immission effects in receiving water system. -Groundwater disturbance/withdrawal during construction.

4 CONCLUSION

Global warming and climate change are caused by greenhouse gas emissions from human activity, which raise the atmosphere's temperature. For the Paris Agreement to remain in effect, emissions must be lowered by 45 percent by 2030 and reach zero by 2050. This paper has analyzed the carbon capture technologies along with their advantages and disadvantages, and the challenges associated with are also highlighted the environmental impacts. The main carbon capture options are post-combustion, pre-combustion, and oxyfuel combustion. Post-combustion capture via chemical absorption using monoethanolamine (MEA) is often the most mature and widely used technique in power generation. Also, oxyfuel combustion capture has a new trend due to its advantages but needs to be developed more to reduce costs and improve efficiency. The importance of the effect on the environment is considered as how it benefits and makes risks. To achieve 14% of the cumulative emissions reductions needed between 2015 and 2050 in a 2 Degrees Scenario, we need to consider future development and cost-effective, efficient ways for carbon capture and storage by overcoming challenges. Crucial pieces of information are provided through the brief case study of the world's first fully integrated carbon capture and storage coal fire power plant, which has used post-combustion carbon capture technology for the process to have an idea about challenges and how they solved them.

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