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Investigation of the feasibility and efficiency of implementing carbon capture and storage technologies in downstream facilities: To mitigate greenhouse gas emissions

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Abstract

This research work investigates the feasibility and efficiency of implementing Carbon Capture and Storage (CCS) Technologies in Downstream Equipment such as in refining and processing, distribution and marketing, petrochemical production and retail sales as ways to mitigate greenhouse gas emissions. Considering the world is in urgent need to cut the emissions of greenhouse gases in order to deal with the challenge of climate change. Most mitigations have targeted carbon dioxide (CO_2), because it is the major agent in global warming. The research focuses on three primary CCS techniques: post-combustion capture, pre-combustion capture, and oxy-fuel combustion. These technologies are unique because they stand out as the only technologies that permit the continued use of fossil fuel powered sources while reducing the amount of CO_2 from these sources. Post-combustion method is best suited for retrofitting existing power plants, its challenges of energy and operation costs would be addressed if there is advancement in chemistry solvent, process efficiency and integration with renewable sources. Pre-combustion method Capture CO2 with 90% efficiency and produces hydrogen as a clean fuel, its viable for new-build plants. Oxy-fuel combustion simplifies CO_2 capture by producing a pure CO_2 stream, also ideal for newly installed facilities. This research also discovered CCS applications in enhancing oil recovery, industries decarbonization, and limiting emissions in sectors necessary for CCS. High costs, infrastructure requirements, and regulatory needs, are few challenges. Each technology fits different need, but their economic viability would be to balance the cost, efficiency and suitability to existing or new installed facilities

Keywords: Post-combustion; Pre-combustion; Oxy-Fuel combustion; Chemistry solvent; Retrofitting; Downstream; Greenhouse gas.

1. Introduction

Considering the world is in urgent need to cut the emissions of greenhouse gases in order to deal with the challenge of climate change, most mitigations have targeted carbon dioxide, CO_2, because it has been considered a major agent in global warming. To help solve this challenge, state-of-the-art technology called carbon capture and storage (CCS) collects CO_2 emissions from industrial sources before they reach the atmosphere and stores them safely underground (Boot-Handford, 2014). This technology has the potential to drastically cut CO_2 emissions, and this is of great relevance in shifting into a low-carbon economy. Application of CCS in industries related to steel, cement, and energy production presents an effective measure for cutting greenhouse gas emissions without giving up on important industrial activities.

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CCS remains an important tool in this fight against the peak of climate change because of its inherently appropriate position that bridges the gap between the fossil fuel-based power currently in place and the sustainable energy solutions for the future, all the more so considering the impossibility of decarbonization for some sectors. (Pires, 2011) and (Skullman, 2024).)

This technology is a process of reduction of the amount of CO_2 released into the atmosphere from energy production, industrial activities, and other sources, hence scientifically referred to as Carbon Capture and Storage. (Ibigbami, O. A., Onilearo, O. D., & Akinyeye, R. O., 2024). A very major weapon in the fight against climate change involves capturing CO_2 emissions and storing them in such a manner that they are not allowed to contribute towards global warming. (Aldy, J. E., & Halem, Z. M., 2024). Here's how it works:

1.1. Major approaches in CCS

1.1.1. Capture

Large point sources of CO_2 may include, but are not limited to, cement mills, power plants, refineries, and other industries. (Lau, H. C., & Tsai, S. C., 2024).

1.1.2. Transport

After capture, the CO_2 is compressed and transported to a storage site, usually by pipeline, but also by ship or other means (Ansari, H. D., & Sangwai, J. S., 2024).

1.1.3. Storage

This involves injection of CO_2 into deep geological subterranean formations that will retain them for all effective purposes: coal beds, deep saline aquifers, and depleted oil and gas fields. (Bashir, A., Ali, M., Patil, S., Aljawad, M. S., Mahmoud, M., Al-Shehri, D., ... & Kamal, M. S., 2024). These formations are typically located deep underground, ensuring that the CO_2 does not escape back into the atmosphere.

2. Overview

These technologies have been proposed as the best way of reducing or completely eliminating carbon footprints left behind in the environment and focusing in the downstream sector by industrial activities and other individual human activities that contribute to global warming and cohabitation of human populations with ecosystems. These technologies are one of a kind because they stand out as the only technologies that permit the continued use of fossil fuel power sources while restricting the amount of CO_2 these sources can produce. (Goren, A. Y., Dincer, I., Gogoi, S. B., Boral, P., & Patel, D, 2024). Among the downstream industries in petrochemicals, natural gas processing, and refining, carbon capture and storage technologies have become indispensable in every aspect of reducing greenhouse gas emissions. Here are some of the primary CCS technologies that are being utilized in the downstream sector. This overview looks at these technologies in different perspectives, examining their pros and cons in section three (methodology) of this review work.

We have three major technologies mapped out for reducing the greenhouse gas in the downstream sector: post-combustion capture, pre-combustion capture, and oxy-fuel combustion. Below is a detailed explanation of each method, accompanied by a description of visual representations.

2.1. Post-Combustion Capture

- **Post-combustion**: In this process, CO_2 is captured after the burning of the fossil fuel. This is normally done by chemical solvents, normally amines which extract the CO_2 from flue gas, which is the gas mixture released after the burning. (Raganati, F., & Ammendola, P., 2024) The technique can be retrofitted at already existing industrial facilities and power plants.. (Verhaeghe, A., Bricteux, L., Demeyer, F., Blondeau, J., & De Paepe, W., 2024)

This entails extracting CO_2 from combustion-by product flue gases. Typical methods comprise:

- **Chemical Absorption**: CO_2 is absorbed from gas streams by using solvents such as amines. The resultant solvent is then heated up to separate the CO_2. (Khan, S. N., Abbas, F., Enujekwu, F. M., Ullah, S., Assiri, M. A., & Al-Sehemi, A. G. , 2024)

- **Adsorption**: CO_2 adsorption can be understood as binding to solid materials at high pressure and being released at lower pressure (Baskaran, D., Saravanan, P., Nagarajan, L., & Byun, H. S., 2024)
- **Membrane Separation**: Separation based on selective membranes by either chemical affinity or size, to separate CO_2 from other gases. (Hu, L., Bui, V. T., Esmaeili, N., & Lin, H., 2024).

2.1.1. Important Steps

- When fossil fuel is burnt in air,
- CO_2 and other gases are freed in the flue gas that results.
- CO_2 capture by the process of absorption in liquid solution is one of them.
- The separated CO_2 is further compressed for storage and transported. (Raganati, F., & Ammendola, P., 2024)

The power plant depicted in the diagram below has a sizable stream of flue gas that leads to an absorber where CO_2 is collected. The remaining gases are subsequently expelled through the plant's exhaust, and the separated CO_2 is compressed and stored.

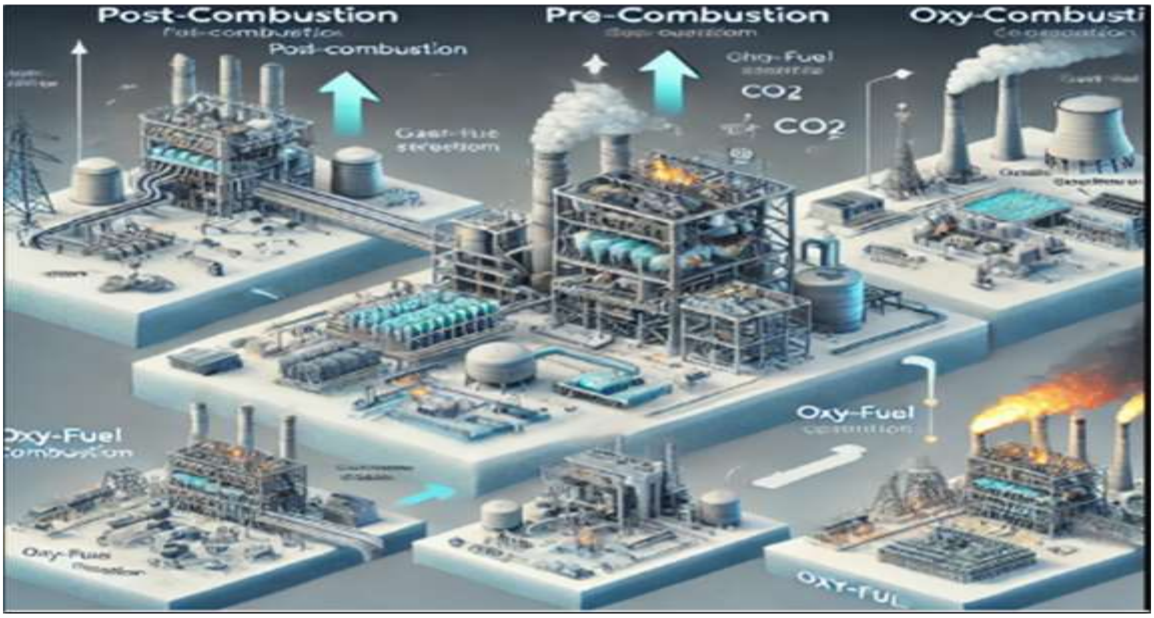

Figure 1 A detailed representation of the three main methods of CO2 capture for Carbon Capture and Storage (CCS)

Figure 2a,b. Shows detailed steps (process flow) of how CO_2 Capture through Post Combustion technology in a Coal Fired Plant is achieved. (BBC NEWS| Science and Environment; Post Combustion CCS Technology, n.d.)

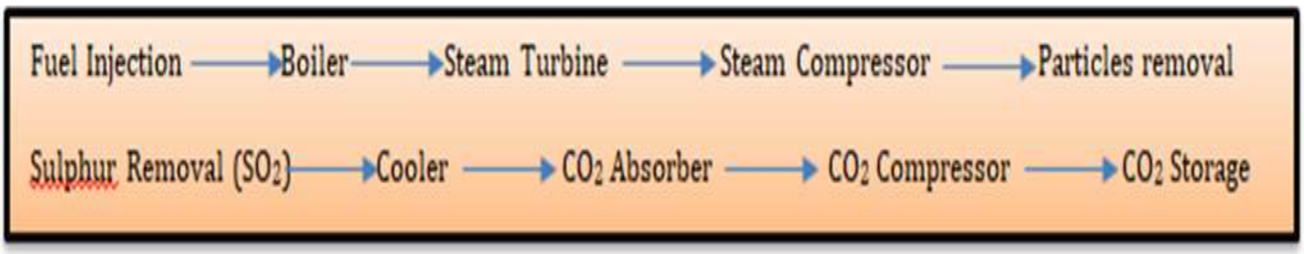

Figure 2a Post Combustion process flow

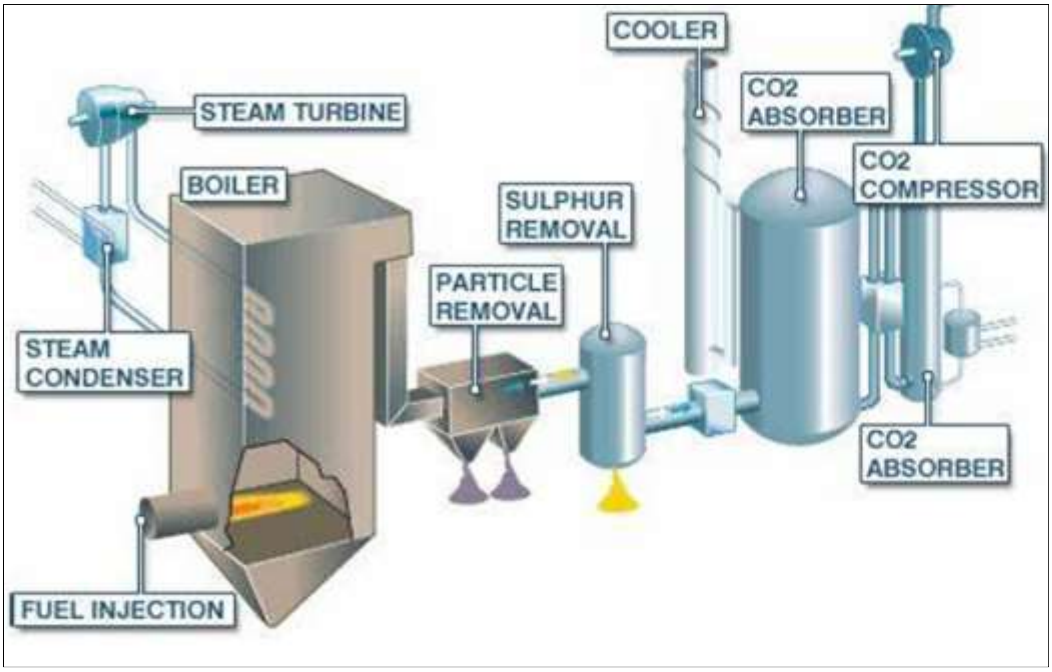

Figure 2b Post Combustion process flow

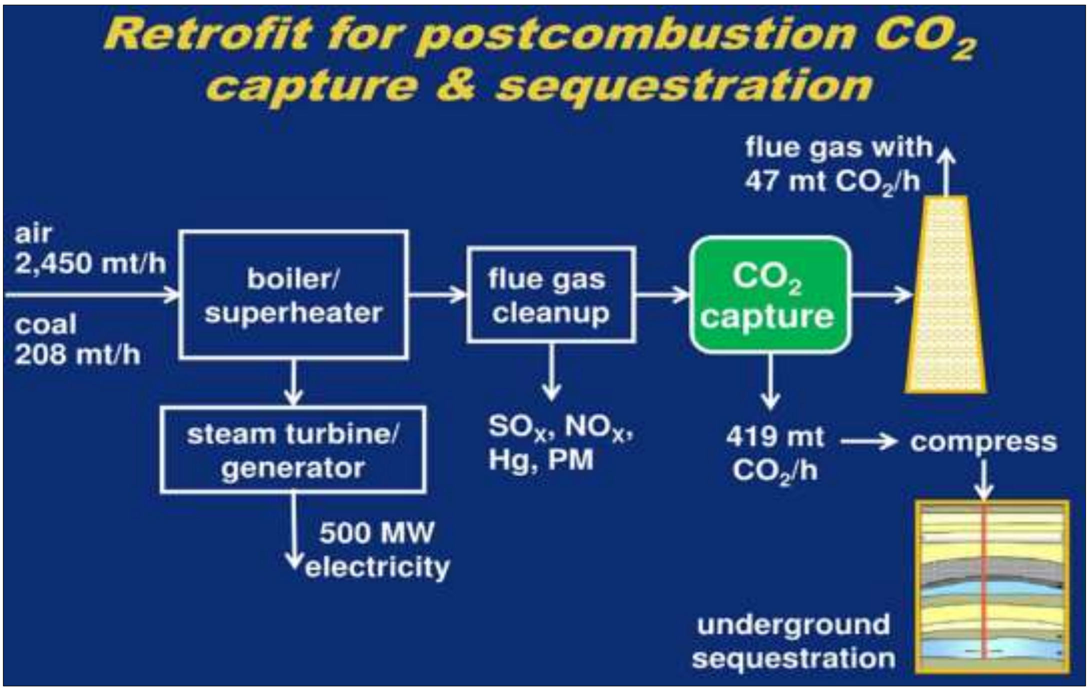

Figure 3 Block diagram of CO2 capture and Storage (Carbon Dioxide Capture by Adsorption: Traditional and Non-traditional Approaches, n.d.) via post combustion

2.1.2. Applicability of this technology

The Post Combustion technology is best suited for:

- Existing Coal Fired Power Plant
- Existing and New Gas-Fired Power Plant

2.2. Pre-Combustion Capture

Pre-combustion: In pre-combustion capture, CO_2 is separated before the fuel combustion process. The process involves gasification of the fossil fuel like coal or natural gas into a mixture of hydrogen and carbon monoxide (syngas). (Law, L. C., Gkantonas, S., Mengoni, A., & Mastorakos, E., 2024) Next, in a procedure called the water-gas shift reaction, the CO reacts with the water to form CO_2 and more hydrogen. (Choi, Y., Sim, G. D., Jung, U., Park, Y., Youn, M. H., Chun, D. H.,. & Koo, K. Y. , 2024). The CO_2 is captured, and the hydrogen can be used as a clean fuel. The process is as follows:

- **Fuel Feedstock**: In a fossil fuel-gasifier, the feedstock comes in solid or liquid form from coal, natural gas, or biomass.
- **Partial Oxidation**: This is a process whereby fuel, with the addition of oxygen or air, undergoes partial oxidation inside a gasifier to produce a mixture of carbon monoxide and hydrogen, more normally referred to as syngas. (Koirala, 2024)
- **Syngas Production**: Syngas leaves the gasifier and goes to the shift reactor.
- **Shift Reactor**: In this reactor, also known as a "water-gas shift reaction," carbon monoxide and water vapor combine to yield more hydrogen and CO_2.
- **CO_2 Capture**: It is separated in order to compress, transport, and store the CO_2.
- **Hydrogen Production**: Hydrogen produced would then be used as a clean fuel- either electricity generation or for other industrial uses.

Pre-combustion capture is a frequently used technology that helps separate CO_2 before combustion, facilitating capture and lowering emissions.

The figure 4 below is the gasification reactor, there the fuel is converted into syngas. A shift reactor then converts the carbon monoxide to CO_2, that is captured, leaving H_2 to be used in the power generation or other industrial usages.

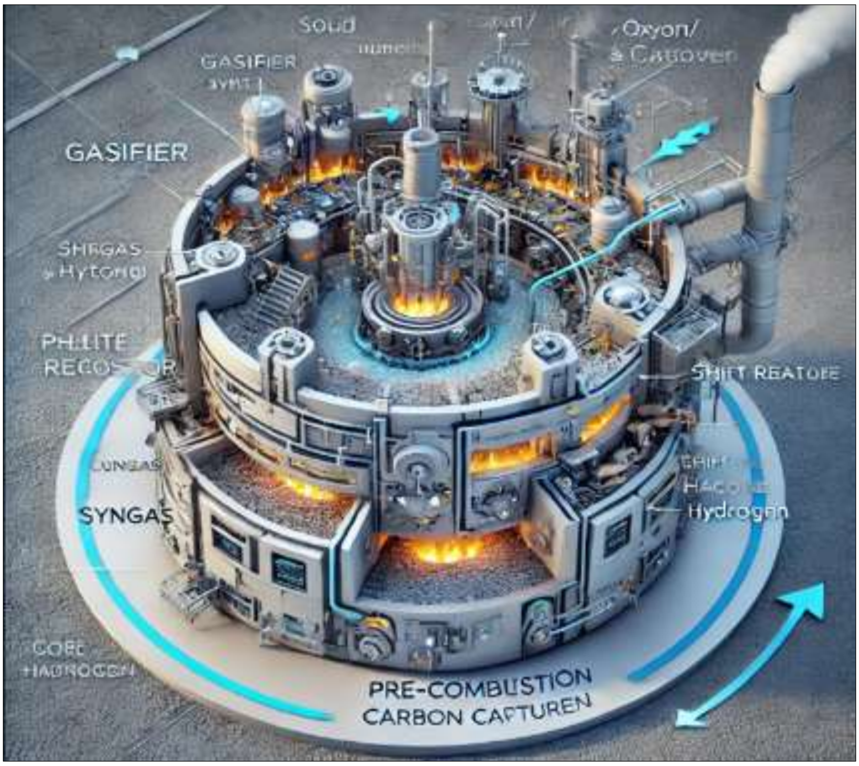

Figure 4 Pre-Combustion Gasifier

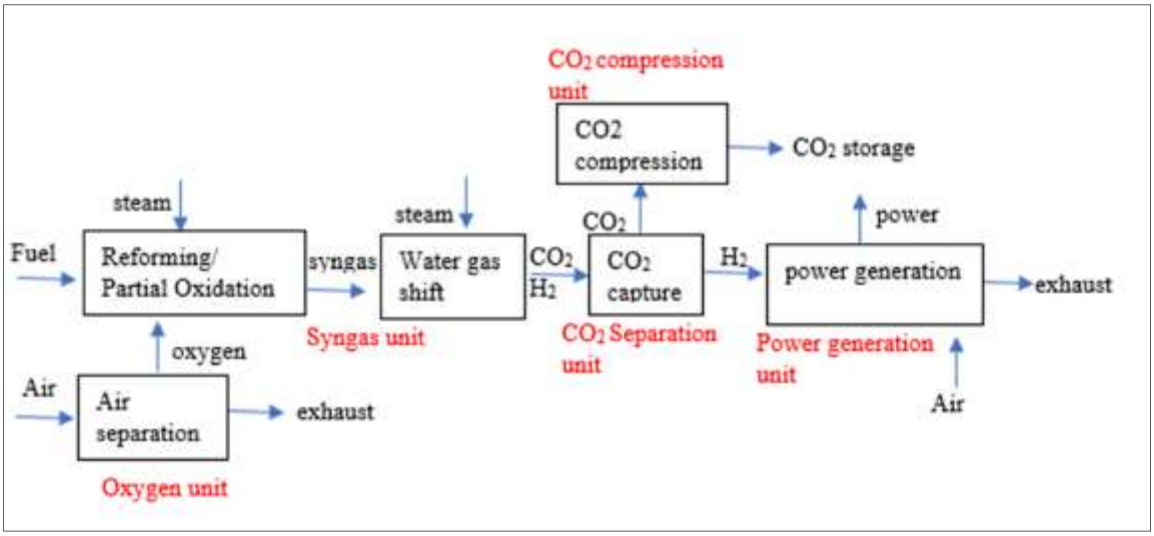

Figure 5 Block diagram showing workflow of the Pre-Combustion technology

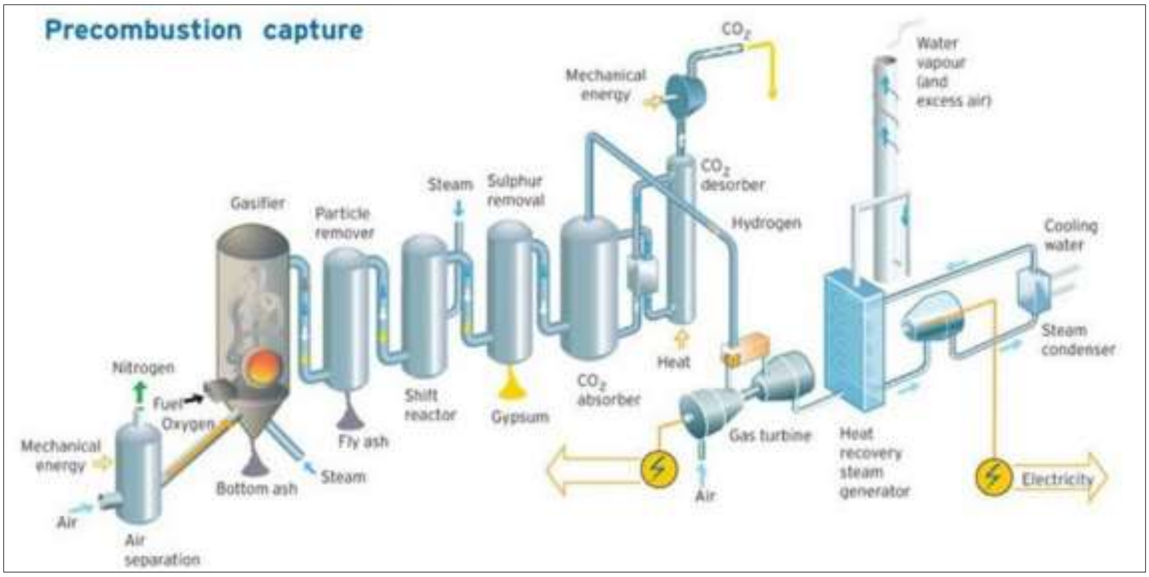

Figure 6 The pictorial unit flow (process flow) of the Pre-Combustion Technology (Research Gate, n.d.)

2.2.1. Applicability of Pre-combustion Technology.

Pre-combustion CO2 capture is best suited for:

- New-build power plant
- Hydrogen production system

2.3. Oxy-Fuel Combustion

Combustion of fuel in oxygen: When fuel is combusted in oxygen, the flue gas (CO_2 and water vapour) will emit almost pure CO_2. When the combustion of fossil fuels takes place in almost pure oxygen instead of air, the flue gas formed will contain mainly CO_2 and water vapor. It then condenses the water vapor, where the pure CO_2 is left behind to be captured.

2.3.1. Key Activities

- Fuel combusts in pure oxygen with major products being H_2O vapor and CO_2.
- The condensation of water vapor leaves to be captured the pure CO_2.

- Transportation and storage of CO_2 is in compressed form.

The figure below shows the combustion chamber for the Oxy-fuel burning. A separate unit condenses H_2O vapor, that leaves the pure CO_2- gas stream that is captured enabling for its storage.

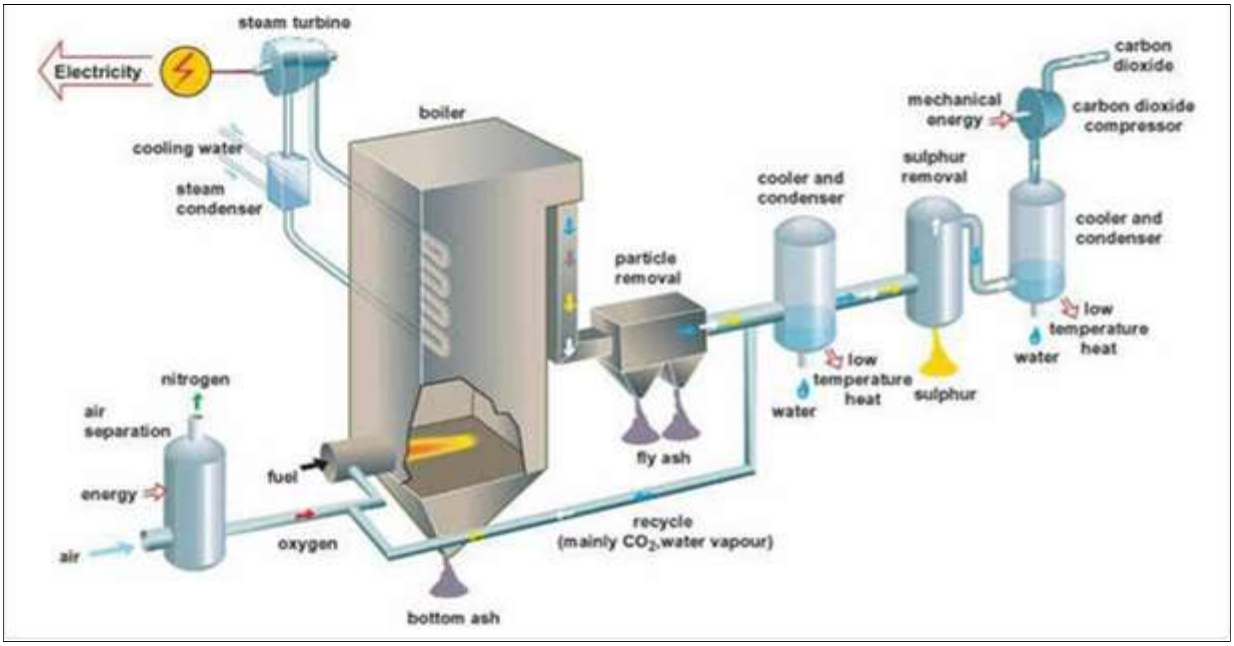

Figure 7 Schematic Diagram of oxy- fuel Combustion CO2 Capture Technology (OCAC Technology in Oxy-Fuel Combustion for Carbon Capture, 2023)

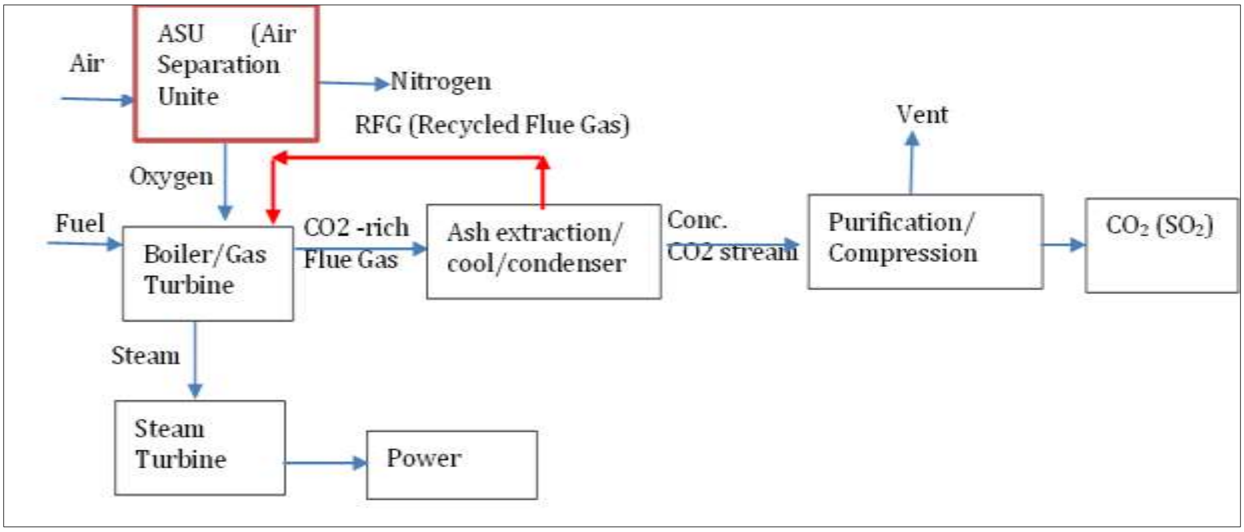

Figure 8 Block Diagram of Oxy-fuel Combustion of CO_2 Capture Technology

The following figures (7 and 8) illustrate the model of an oxy-fuel combustion system. It contains the main items: the fuel supply, oxygen supply, combustion chamber and the CO_2 and water vapour output streams.

Their effectiveness as capture devices varies with the industry involved and with the particulars of the emission, but all are central to CCS. Pre-combustion and oxy-fuel capture techniques are better suited for new, integrated systems; post-combustion, on the other hand, is often used with power plants already in operation.

2.3.2. Application and Importance

- **Climate Change Mitigation**: CCS is among the technologies that could help reach the global climate targets since they can reduce industrial CO_2 emissions.
- **Enhanced Oil Recovery**: EOR is a process in which captured CO_2 is injected into the existing oil field to increase the extraction of oil from the ground.
- **Decarbonization of Industry**: CCS applications in some hard-to-decarbonize industries like chemical processing, steel manufacturing, and cement production.

CCS, though promising high positive environmental inhabitation, has disadvantages including unreasonably high cost of establishment, requires large infrastructure, and poses long-term CO_2 leakage issues. (Anderson, 2004)

3. Methodology

In this section, we will look at the pros and cons of the three CCS technologies and how we can combine their applications for effective reduction of the greenhouse gases in the downstream environment. And where each technology is best suited for. Among the three, the most used and applied technology happens to be post-combustion carbon capture, where CO_2 emitted from factories and power plants is absorbed. The Pros and Cons of post-combustion carbon capture and storage are given below:

3.1. Pros

- **Compatibility with Existing Infrastructure:** Consequently, it does not require major changes in the combustion process and is thus also appropriate for retro-fitting with post-combustion capture equipment at already existing industrial facilities and power plants. The use is thus applicable for practical emission reduction in continued operations.
- **Proven Technology:** Among the more advanced and established CO_2 capture technologies, this technology has been demonstrated to be effectively scaled up and operated in various pilot projects. E.g. The Canadian Boundary Dam Carbon Capture and Storage Project. The first Post-combustion CCS method in commercial scale, capturing 1 million CO_2 annually from and integrated coal-fired plant.
- **Applicability to a Range of Fuels**: Biomass, natural gas, and coal can all be combusted in different power plants using this technique. It is such a versatile technology that post-combustion capture has been extended to many industrial and energy applications.
- **Modular and Scalable**: The system can easily be built as a modular unit, and scaling up or down depending upon the capacity required or size of the plant is quite easy.
- **Less R&D Cost**: Because of the mature nature of the technology, it would generally be less in R&D expense for many industries than many newer and upcoming carbon capture systems.
- **Improved Efficiency Over Time:** Enhancements in solvent technology, process optimization, and heat integration can lower energy penalties and increase efficiency related to post-combustion capture.

3.2. Cons

- **High Energy Consumption:** The solvent regeneration, for example, requires very high energy use in an amine-based system. Due to these penalties, the general efficiency of the power plant might go down and fuel consumption could increase.
- **High Operational Costs:** The cost of capturing CO_2 post-combustion is usually higher as compared to other CCS methods. This is because it involves extra equipment, such as solvent handling systems and absorption columns, each requiring intensive energy operation.
- **Limited Capture Efficiency:** In general, post-combustion capture is more effective for the low CO_2 concentrations in flue gases. Greater capture efficiencies greater than 90% are achieved cost-efficiently hardly without significant cost increase for post-combustion capture.
- **Large Space Requirement:** This is a space-consuming installation of post-combustion capture, which is one of the major constraints for retrofitting the existing plants.
- **Corrosion and Environmental Impact:** More aggressive solvents, such as amines, may give rise to equipment corrosion, which leads to a lot of maintenance problems, possibly with a negative environmental consequence of degradation products from the solvent.
- **Requires Additional CO_2 Compression:** Following capture, CO_2 has to be compressed for transportation and storage. It introduces another energy-intensive process to an already energy-intensive process, increasing operating cost and energy usage.

- **Potential Health and Safety Risks:** Application of chemical solvents can actually be very dangerous from the point of view of health and safety. Therefore, careful handling and monitoring techniques must be developed especially in large-scale applications.

As said earlier, pre-combustion carbon capture is a process in which CO_2 is absorbed before fuel combustion in a power plant or during any other industrial process. It mostly consists of a process involving gasification or reforming of a main feedstock-such as coal and natural gas-into a hydrogen-CO_2 mixture. Once the hydrogen is separated from the CO_2, the fuel can serve as a clean one. Pros and Cons of pre-combustion carbon capture and storage are as follows:

3.3. PROS

- **High CO_2 Capture Efficiency:** Among the technologies, pre-combustion capture has several advantages over post-combustion capture because it can attain a very high CO_2 capture rate, usually in excess of 90%, owing to the high concentration of CO_2 within the gas stream.
- **Less Energy Penalty:** Since CO_2 is at a higher pressure and concentration during pre-combustion, capturing it often uses less energy than post-combustion systems. This will lower the energy penalty while having no effect on the power plant's overall efficiency.
- **Production of Hydrogen:** The pre-combustion capture results in the generation of hydrogen as a by-product, which is a valuable by-product. The utilization of hydrogen as a clean fuel for the industry, transport, and production of power in support of decarbonization is also of importance.
- **Improved Plant Efficiency:** Pre-combustion systems have a better chance of performing in a plant as a whole since they transform fuel into greener energy sources such as hydrogen, while plants that use combustion do not.
- **Better Integration with Facilities of IGCC:** Pre-combustion works well with the facilities of IGCC (i.e Integrated Gasification Combined Cycle), which gasify fuel and capture CO_2 before it gets burned. Because of this, it becomes a desirable choice for large-scale and highly efficient power generation.
- **Lower Volume of Gas to Process:** Less Gas to Process: In comparison with post-combustion systems, less gas is processed in pre-combustion systems to separate out CO_2. As a result, all capture equipment is smaller and less expensive.

3.4. CONS

- **High Initial Capital Cost:** High Initial Capital Cost: Pre-combustion systems have a high initial capital cost compared to systems that capture post-combustion, since the process involves several complicated pieces of equipment such as gasifiers, shift reactors, and CO_2 separation units.
- **Less Retrofitting Opportunities:** In comparison with post-combustion capture, pre-combustion is more difficult to retrofit into currently operating power plants. Because it would most likely be viable in new build projects, like IGCC plants, it is a less popular technology for the abatement of emissi ons from existing capital stock.
- **Complex Process Integration:** Hydrogen separation and CO_2 collection, when integrated with gasification, is a very complex process, and many optimizations need to be performed, which increases the operational cost and complexity.
- **High Hydrogen Production Cost:** Though there do exist some advantages of hydrogen production, there also are some disadvantages. Technologies of pre-combustion are less economically viable to produce hydrogen unless there is strong demand for the gas, as they may be more expensive than other ways.
- **Water and Environmental Concerns:** Water and Environmental Issues: The pre-combustion and gasification operations may emit additional pollutants, such as sulphur compounds, that will require extra cleaning and mitigation steps. Such processes can also use significant amounts of water,
- **Limited Applicability to Low-Carbon Fuels:** Limited Applicability to Low-Carbon Fuels: High-carbon fuels such as coal and natural gas are the best candidates for pre-combustion. The low or no compatibility of this carbon capture option with low-carbon or renewable fuel options makes it less useful in a decarbonized energy system.
- **Technical Challenges with Scale-Up:** Technical Challenges in Scale-Up: Pre-combustion capture at large scale presents technical challenges for dependability and efficiency at scale, likely well beyond extensive pilot testing and optimization.

Finally, the oxygen-fuel combustion is another CCS technology wherein the fuel-medium-sized coal, natural gas, or biomass-is combusted in a mixture of recovered flue gas and pure oxygen rather than ordinary air. Consequently, this makes the separation and capture of CO_2 much easier by producing a flue gas stream that is majorly made up of CO_2 and water vapor. Pros and Cons related to oxy-fuel combustion for CCS are underlined in the following points.

3.5. PROS

- **High Purity CO_2 Stream:** High Purity CO_2 Stream: When fuel is combusted with pure oxygen, water vapour and CO_2 comprise the majority of the flue gas. It is easier and less energy intensive than other means because the remaining CO_2 is highly concentrated and reasonably straightforward to capture once the water is condensed.
- **No Need for Complex Post-Combustion Capture:** Post-combustion Capture, Simple Not Required: As the majority of the flue gas consists of CO_2 and water, less expensive and simpler post-combustion capture methods are not necessary, for example, amine scrubbing.
- **Enhanced CO_2 Capture Rates:** Higher CO_2 Capture Rates: In oxy-fuel combustion, high capture rates of CO_2 can be achieved and have often been reported to exceed 90%; this then makes this quite an effective carbon capture technique.
- **Potential for Near-Zero Emissions:** Oxy-fuel combustion allows for near-zero CO_2 emission through flue gas recycling with near-total capture of the produced CO_2. This will drastically reduce the carbon footprint of a plant.
- **Scaled-down NO_x Emissions:** Smaller NO2 Emissions; the atmospheric nitrogen is not being combusted, less NO_x is given out into the atmosphere, a kind of pollution that is considerably harmful. Besides the reduction in the cost of treatment against pollution, it might imply an improvement in local air quality.
- **Better Integration with Carbon Utilization:** Better Integration with Carbon Utilization: A high-purity CO_2 stream could be produced for direct value, with the potential for additional revenues through its use in producing chemicals, enhanced oil recovery (EOR), and other industrial applications.
- **Easier Transportation and Storage:** Easier Storage and transit: The stream of CO_2 is generated at higher pressures in most oxygen-fuel systems, which limits the energy required for compression and storage transit, therefore reducing downstream costs.

3.6. CONS

- **High Energy Consumption to Generate Oxygen:** One of the major drawbacks of oxy fuel combustion is the high energy consumption in order to generate oxygen. Separating oxygen from air could increase the overall energy penalty due to the use of energy-intensive techniques such as (ASUs), or cryogenic air separation units.
- **High Capital and Operational Costs:** High Capital and Operational Expenses: This technology, when related to other CCS systems, is not as attractive to be implemented at existing power plants, since huge capital investment and high operational expenditures are required for this specialist equipment, such as ASUs and modified combustion chambers.
- **Complex Process Integration:** Integration of Complex Process: For the intelligent integration of CO_2 capture, combustion, and oxygen production, detailed planning and optimization will have to be done. If this is complex, then operating problems may arise with a need for more maintenance.
- **Water Management Problems:** Because of the high-water content in the flue gas, an effective water management and condensation system has to be maintained. Water content will have to be carefully controlled so that performance of the system cannot be compromised, and corrosion is avoided.
- **Limited possibility of retrofit:** Conversion of already operating power stations into oxy-fuel combustion is extremely burdensome and costly-the boilers and turbines would need significant alterations, not to mention the supply of oxygen. This works a bit better for recently constructed plants than for the older ones.
- **Air Ingress Problems:** Even small air leakage into the combustion chamber can result in substantial dilution of the CO_2 stream, making CO_2 purification more cumbersome and expensive; this is an operating hassle to be avoided by careful sealing and monitoring.
- **Less advanced than other CCS Technologies:** Whereas oxy-fuel combustion has been studied and demonstrated in a number of pilot projects, the technology is still less advanced than post- and pre-combustion; there has not been much wide usage of this technology.

3.7. Other CCS technologies includes

- **Direct Air Capture (DAC):** The newest of methods is called DAC, or Direct Air Capture. This is a comparatively new technique wherein CO_2 is directly drawn from the atmosphere by using chemical procedures. In such cases, after capture, CO_2 can be stored or applied in many ways.
- **Carbon Utilization:** Carbon Utilization: Captured CO_2 has several uses, such as in enhanced oil recovery by injecting gas into the oil reservoirs to enhance efficiency in extraction, and as feedstock for the production of chemicals and fuels.
- **Geological Storage:** Geological Storage: After capture, CO_2 is transported and stored underground in geological structures such as saline aquifers, unmineable coal seams, and depleted oil and gas fields.

- **Bioenergy with Carbon Capture and Storage (BECCS):** BECCS, the production of energy from biomass combined with carbon capture and storage. Biomass is a carbon-neutral energy source, but if CO_2 emissions during its use are captured and stored, the emissions will be negative.
- **Process Modifications:** Process Modifications: Facilities can make certain changes in their processes to reduce CO_2 emissions. This could be through the application of low-carbon technologies, optimization of energy efficiency, and improvement in operating conditions.

4. Challenges and considerations

- **Cost**: The technology of CCS application is expensive, and funding and economic viability remain an extremely hot topic.
- **Infrastructure**: Pipelines are part of the infrastructure required for transportation and storage of the capture CO_2 gas.
- **Regulatory Framework**: Properly designed policy and regulation form the backbone of successful CCS deployment.

If adequately deployed in the downstream facilities (refining and processing, distribution and marketing, petrochemical production and retail sales), such technologies may come out to be fantastically helpful in reducing GHG emissions and, therefore, dealing with climate change.

5. Discussion

We shall compare the three technologies covered in this review work for CCS, making use of the above pros and cons. And thereafter make recommendation on the efficient applications on the downstream facilities to mitigate greenhouse gas.

This table compares the three technologies across various factors, highlighting their strengths, limitations, and potential for future application.

Table 1 Three technologies across various factors, highlighting their strengths, limitations, and potential for future application

CCS Technology	Post Combustion capture	Pre-Combustion capture	Oxy-Fuel Combustion
Description	Captures CO_2 from flue gases following fuel combustion,	First converts the fuel into hydrogen and CO_2 in advance of combustion, then captures the CO_2,	The combustion of fuel in pure oxygen only the flue gas is essentially water and CO_2.
Primary Advantage	Can be applied to existing industrial plants and power stations.	high degree of separation of CO_2, with hydrogen as a valuable by-product	Will result in virtually pure stream of CO_2 that will have less complicated collecting process
Key Benefit	Widely applicable and proven technology for existing infrastructure	Enables hydrogen production, contributing to clean energy	High CO_2 capture efficiency with minimal impurities
Major Drawback	High energy consumption, operational costs, and environmental concerns.	High capital cost, complex integration, and limited retrofit potential.	High energy demand for oxygen production and elevated costs.
Best Suited For	Retrofitting existing plants to reduce emissions	New-build power plants and industries with hydrogen integration potential.	New plants designed specifically for oxy-fuel combustion.
Challenges	Requires improvements in solvent chemistry and process efficiency to reduce energy consumption	Expensive setup and difficult to retrofit into existing plants.	Requires technological advancements to reduce energy costs for oxygen production.

Potential for Future Use	Integration with renewable energy and improved solvent technology could enhance efficiency and reduce costs	Important for decarbonizing new power plants if hydrogen markets become economically viable.	Could become more competitive if the energy demand for oxygen production is reduced.
Retrofit Potential	High — can be applied to existing plants.	Low — more suitable for new facilities.	Low — not ideal for retrofitting, better for new installations.

6. Conclusion

In conclusion, there are specific advantages and challenges in each of the three CCS technologies: Post-combustion, Pre-combustion, and Oxy-fuel combustion. Now, the Post-combustion capture is generally best suited for retrofitting existing power plants (that is, it is compatible and adaptable with already operating power plant), though it involves immense costs in energy and operation. But these challenges would be addressed if there is advancement in chemistry solvent, efficiency in the process and integration with renewable sources. Pre-combustion capture is ideal for new plants and critical for Hydrogen production which proffer solution for clean energy. And lastly the Oxy-Fuel combustion capture, though highly expensive and complex to install, it is highly efficient for producing hydrogen, Combustion of oxygen and fuel gives high-purity streams of CO_2 at high capture efficiency, but because of oxygen production, this process is considerably more energy-intensive and hence best applied to recently built plants. The knowledge gap here is to make the cost of hydrogen production and marketing competitive.

The most appropriate or best technology among the three is context dependent: post-combustion is the best choice presently for an existing power plants, while pre-combustion and oxy-fuel combustion are best choices for new plants, and when integrated with other technologies, such as IGCC (i.e. Integrated gasification Combined Cycle) or hydrogen production. Finally, each technology fits different need, but their viability and economic importance would be to balance the cost, efficiency and suitability to exiting or new installed facilities. when these aspects are settled and put in place, the decarbonization and reduction of the Green House Gases of energy and other industrial sectors will be achieved especially in the downstream sector.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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