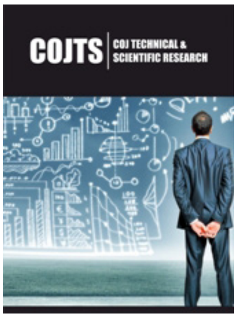
Crimson Publishers
Wings to the Research

Short Communication

CO_2 Capture: Importance and Combustion Processes

ISSN: 2643-7066



Juliana Schultz[1]*, Tarcisio Wolff Leal[1], Amanda Ribeiro da Rocha[2], Glaucia Pantano[2] and Antonio Salvio Mangrich[2]

[1]Department of Environmental Engineering, Federal University of Paraná, Brazil

[2]Department of Chemistry, Federal University of Paraná, Brazil

***Corresponding authors:** Juliana Schultz, Federal University of Parana, Curitiba, Paraná, Brazil

Submission: May 01, 2024

Published: June 11, 2024

Volume 5 - Issue 1

How to cite this article: Juliana Schultz*, Tarcisio Wolff Leal, Amanda Ribeiro da Rocha, Glaucia Pantano and Antonio Salvio Mangrich. CO_2 Capture: Importance and Combustion Processes. COJ Tech Sci Res. 5(1). COJTS. 000602. 2024.
DOI: 10.31031/COJTS.2024.05.000602

Abstract

The development of society brings with it many positive, but also negative aspects. One of the negative aspects is the unbridled release of gasses into the atmosphere, including CO_2. This gas is one of the main contributors to the unbalanced greenhouse effect and global warming, which is why methods for capturing/sequestering this gas need to be investigated more intensively. This communication summarizes why one should focus on this gas and which industrial processes can be used to develop methods/materials/processes for its capture.

Keywords: CO_2 capture; CO_2 sequestration; Greenhouse gases; Global warming

Introduction

The aim of this study was to investigate the origins and effects of greenhouse gasses, to provide a historical overview of emissions caused by human activities and to examine the main methods of CO_2 capture in comparison with the main processes of energy production from fossil fuels.

Greenhouse gases and global warming

The temperature of a planet is determined by the energy balance between the absorption of sunlight and the loss of heat to space. On earth, there is a relatively balanced energy equilibrium that has made the planet habitable for billions of years. When sunlight reaches the earth's surface, it can either be reflected back into space and not warm the earth, or it can be absorbed and warm it (when a planet absorbs energy, some of that energy is released into the atmosphere as heat) [1]. Some gasses in the atmosphere absorb energy and delay or prevent the release (loss) of heat to space. These gasses are known as Greenhouse Gasses (GHGs) and act like a blanket, making the earth warmer than it would otherwise be. This process, known as the greenhouse effect, is natural and necessary to sustain life on earth. However, the unbridled increase in the release of these gasses due to human activities is leading to an accumulation of these gasses in the atmosphere and is changing the earth's climate (global warming) with dangerous consequences for the health and well-being of humans and even ecosystems [2]. The most important greenhouse gasses are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). However, the use of fossil fuels by humans also produces other environmentally harmful gasses such as Carbon Monoxide (CO), Nitrogen Oxides (NOx), sulfur dioxide (SO_2), Non-Methane Volatile Organic Compounds (NMVOC) and particulate matter, which contribute to climate change [3]. Emissions of GHGs have increased with the development and growth of humanity, as can be seen in Figure 1, which shows the emissions for some of the gasses in the period 1990-2019 in $GtCO_2$-eq [4]. Fluorinated gasses (F-gasses) have no significant natural sources, i.e. they originate from man-made activities. There are four main categories of these gasses, which are divided into hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3), with HFCs being the most important from a climatic point of view. These gasses can have a long lifetime in the atmosphere, which can be thousands of years. They disperse easily when emitted and are often only removed from the atmosphere when they are destroyed by solar radiation at high altitudes. Many of these gasses have a very high global warming effect compared to other greenhouse gasses (for example, they reach a value 23,000 times higher than that of carbon dioxide [5], that is, small concentrations can have large effects on global temperatures [6,7]. Nitrous oxide (N_2O) not only originates from human activities such as agriculture (use of fertilizers), fossil fuels, wastewater disposal and industrial processes, but is also naturally present in the atmosphere as part of the nitrogen cycle. Put simply, in the nitrogen cycle, atmospheric N_2 in the soil is bound to ammonia (NH_3) by bacteria and prokaryotes. NH_3 can be converted to ammonium ions (NH_4^+), which can be oxidized to nitrite ions (NO_2^-) and then to nitrate (NO_3^-), a process known as nitrification; these ions formed during nitrification can be reduced by enzymes in the denitrification process, producing intermediates: NO_2^-, NO and N_2O [6,8]. N_2O molecules remain in the atmosphere for less time than fluorinated gas molecules, about 121 years, and can be removed by reactions such as photolysis and reaction with atomic oxygen in the stratosphere. Its impact on global warming is also greater than that of CO_2, but not as great as that of fluorinated gasses. The impact of 1 pound of N_2O on global warming is about 265-298 times greater than that of 1 pound of CO_2 [9-11].

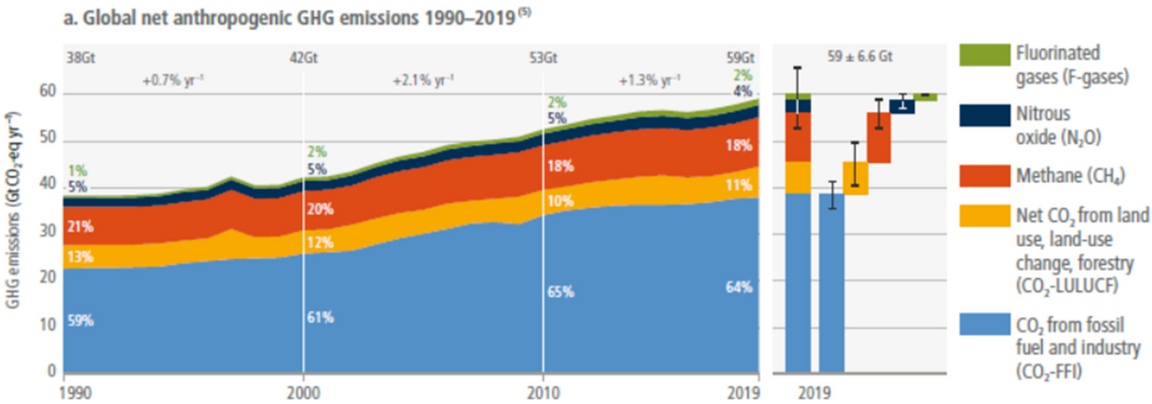


Figure 1: Global net anthropogenic GHG emissions 1990-2019.

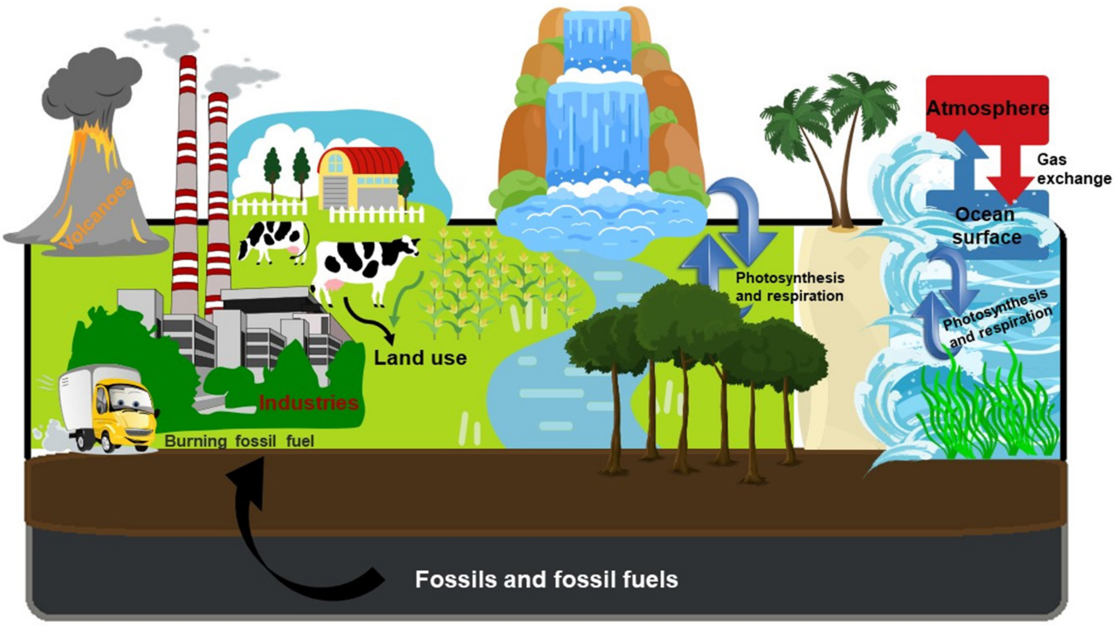


Figure 2: Simplified carbon cycle.

Methane (CH_4) is the second most important greenhouse gas contributing to the rise in global temperature (responsible for about 30% of the increase since the industrial revolution). It can be released from natural sources, e.g. in regions with a high content of organic matter, in reservoirs and lakes that decompose in the absence of oxygen, in termites, in sediments, in volcanoes and through human activities, e.g. through leaks in natural gas systems, in the energy sector, in agriculture and livestock farming. It has a short lifetime of about 12 years, but absorbs much more energy in the atmosphere compared to other greenhouse gasses, can pose explosion risks and can bring ozone (O_3) down to the ground (troposphere), causing serious health problems [12,13]. Finally, and not least, carbon dioxide (CO_2), the most important greenhouse gas, which is almost entirely confined to the lowest level of the atmosphere (troposphere)-the only stratospheric source of CO_2 is a small contribution from methane oxidation [14]. Like N_2O, CO_2 is naturally present in the atmosphere and is part of a cycle, the carbon cycle, in which carbon circulates naturally between the atmosphere, oceans, soil, plants and animals. Figure 2 schematically illustrates this cycle of transformation of inorganic and organic forms of carbon and transportation: Fossil fuels are extracted and used in industry and transportation, releasing CO_2. In land use, all living organisms carry out cellular respiration to obtain energy from the food they consume. During the respiration process, the cell takes in oxygen to break down macromolecules (carbohydrates, proteins and lipids), mainly sugars (glucose and its derivatives), and release CO_2 in agriculture, CO_2 is released at various stages of the process, sometimes carbon is released into the atmosphere by volcanic eruptions, plants and phytoplankton remove CO_2 from the atmosphere in the process of photosynthesis [15]. *In situ* observations and ice core records have shown that the concentrations of some of the above-mentioned greenhouse gasses have increased in recent centuries. Although the terrestrial environment and oceans have absorbed more than 50% (globally) of some of these gasses, concentrations continue to rise, reaching 332ppb for N_2O, 1866ppb for CH_4 and 410ppm for CO_2 in 2019. Concurrent with the rise in GHG concentrations, there has been a rise in global temperature, which increased by 0.8-1.3oC from 1850-1900 to 2010-2019, with the best estimate being 1.07oC (Figure 3). It is likely that well-mixed greenhouse gasses have contributed to a warming of 1.0-2.0oC [16,17].

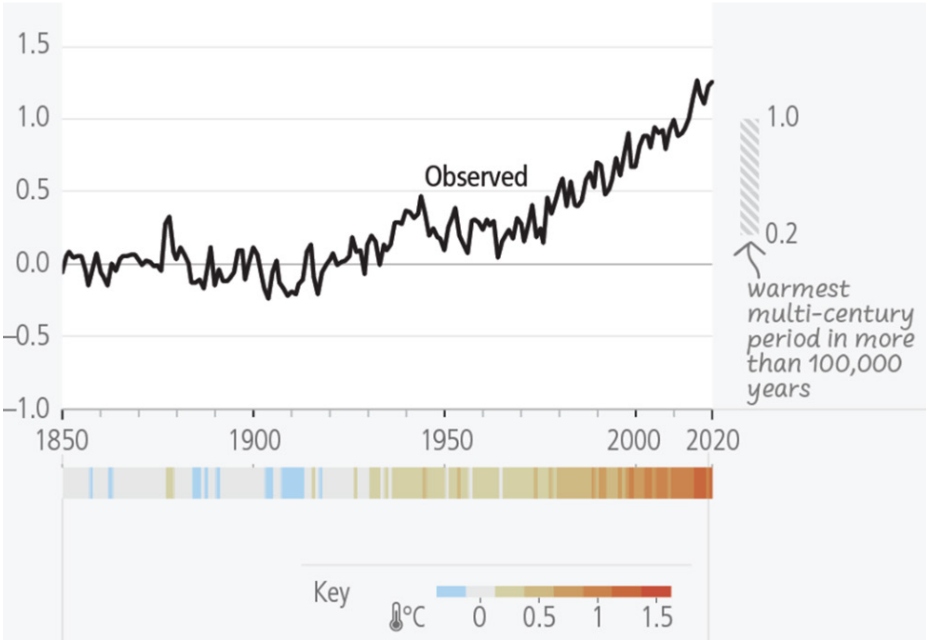


Figure 3: Global temperature variation from 1850 to 2020.

CO_2 as the biggest contributor to the greenhouse effect

The energy source that warms the atmosphere is the heat of the sun in the form of electromagnetic radiation about 10% is ultraviolet radiation, 40% visible light, 49% infrared radiation and 1% X-rays. Of these radiations, infrared radiation has a heating effect, warming the Earth, its atmosphere and various objects [18]. A small part of the infrared radiation that falls on the earth's surface is reflected back into space, but most of it cannot escape the layer of water vapor, clouds and gasses, mainly CO_2 and other greenhouse gasses (Figure 4). This layer of gas acts like the glass panes of a greenhouse or the glass of a car window, allowing solar radiation to pass through and warming the surface and keeping it warm by not allowing the radiated heat to pass through. Therefore, the covering of these gasses in the atmosphere intercepts the infrared radiation that generates heat at the Earth's surface [14,19]. Carbon dioxide is emitted when fossil fuels (coal, natural gas, diesel, etc.), solid waste, trees and other biological materials are burned; covering all sectors of the economy (electricity, transport, construction, industries). It can also be emitted as a result of chemical reactions (cement production) and land use (agriculture, farming) [20]. CO_2 emissions have grown steadily since the beginning of the industrial age, with short gaps in growth due to global economic crises or social instability. Recently, as an example, we had the global COVID-19 crisis, where periods of temporary lockdowns caused a sharp drop in daily global CO_2 emissions. We also saw the positive impact on the environment in many places by reducing production and traffic between cities and regions around the world [21]. Figure 5 shows the main sources of CO_2 releases from 1880 to 2019 as reported by the Intergovernmental Panel on Climate Change (IPCC). In the last decade, CO_2 emissions from fossil fuels reached an average of 9.6±0.5 PgC year-1 (86% of all anthropogenic CO_2 emissions). For 2019, CO_2 emissions (fossil) were estimated at 9.9±0.5 PgC year-1, excluding carbonization.

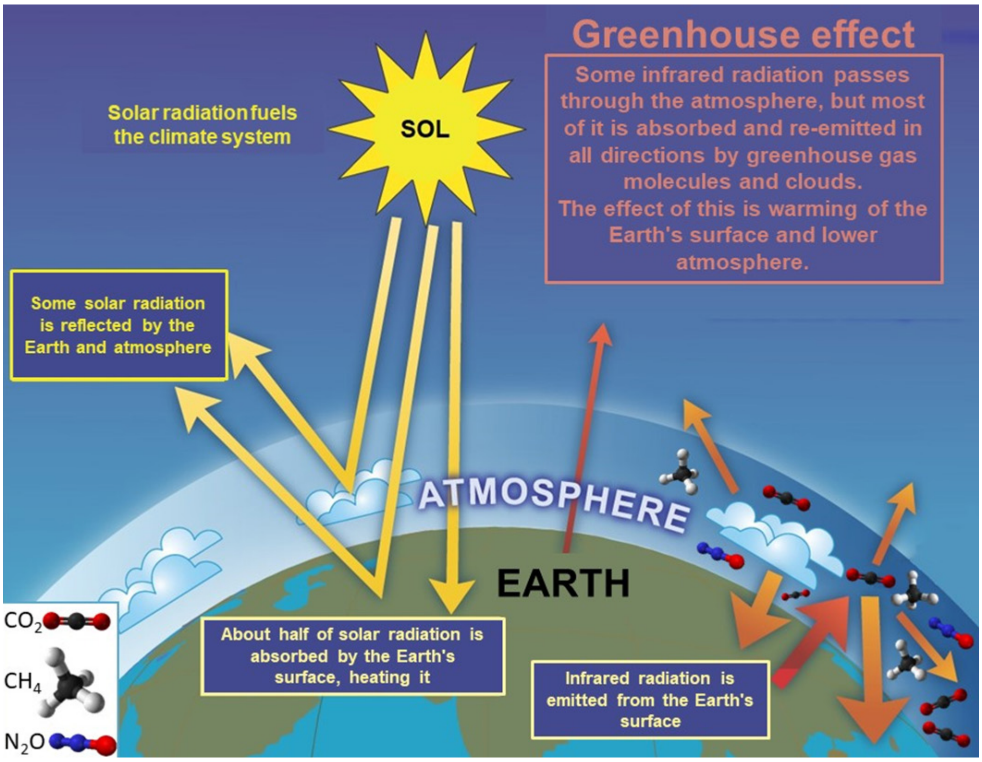


Figure 4: Idealized model of the greenhouse effect.

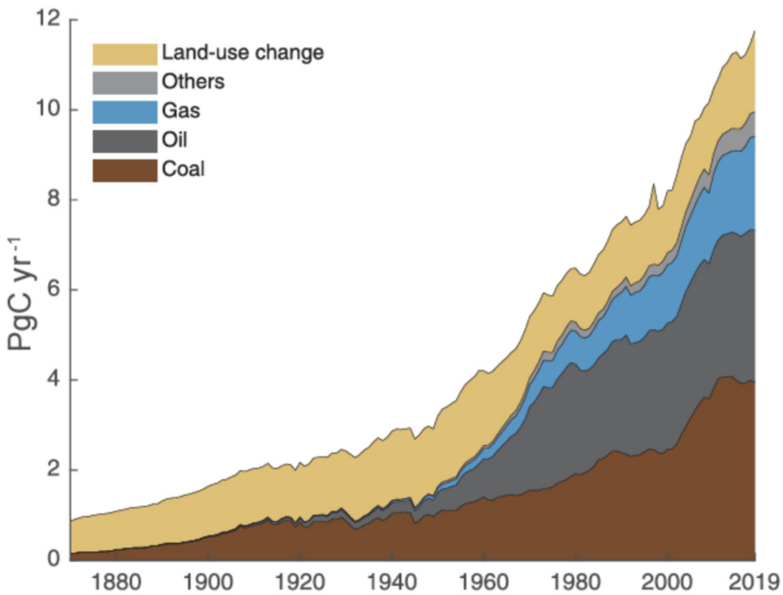


Figure 5: Global anthropogenic CO_2 emissions.

CO_2 capture

Carbon capture technology is a group of processes that aim to produce a concentrated and transportable amount of CO_2 to reduce industrial emissions. It is seen as a way to mitigate climate change, even when renewable energy alternatives are widely available, as CO_2 emissions continue to rise, as shown in Figure 6. Since the 1850s, the concentration of greenhouse gasses has increased, with the increase accelerating since the 1980s and reaching 410ppm in 2019 [22]. According to a report by the International Energy Agency (IEA), global CO_2 emissions (from energy production and industrial processes) will fall by more than 5% in 2020 if the Covid-19 pandemic reduces demand for energy. However, as economic stimulus and vaccine roll-out kicked in, emissions increased by more than 6% in 2021. In 2022, the increase was only 0.9%, but reached a new historic record of 36.8Gt, as you can see in Figure 7 [12]. These high values highlight the need for processes to capture carbon dioxide (CO_2) from the various sources that release it (thermoelectric power plants, wastewater treatment plants for sanitary or industrial wastewater, cement and iron and steel industries, refineries, transportation, etc.). These processes are classified according to the combustion process used: Pre-combustion, combustion with oxygen (O_2) or oxy-fuel and pre-combustion [23-25].

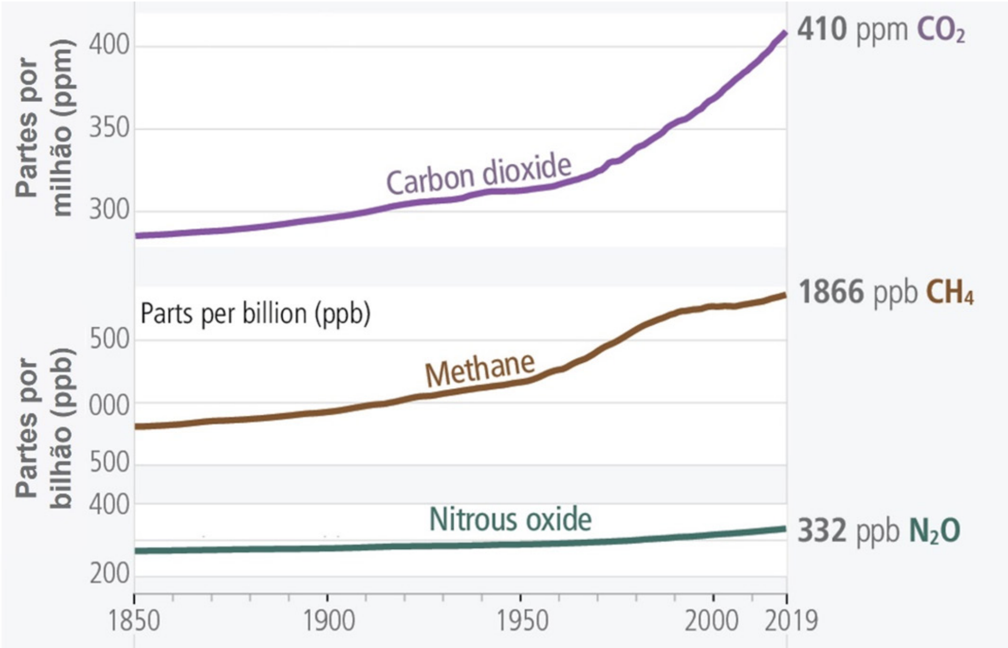


Figure 6: Emission of gases CO_2, CH_4 and N_2O according to the years (1850-2019).

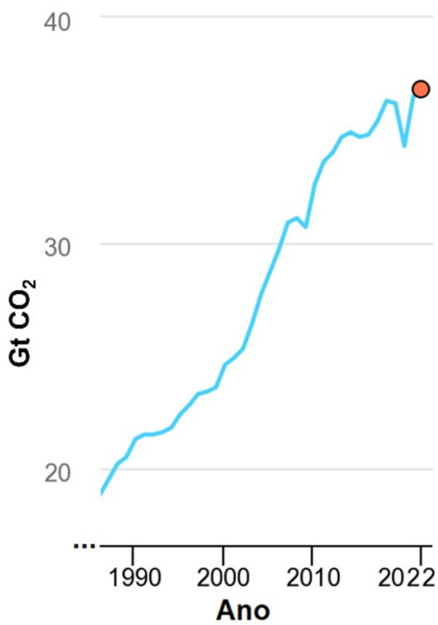


Figure 7: Global CO_2 emissions from energy combustion and industrial processes and their annual variation. This is a work derived by Juliana Schultz from IEA material and Juliana Schultz is solely liable and responsible for this derived work. The derived work is not endorsed by the IEA in any manner.

Pre-combustion

This process was developed in 1774 to produce gas, which was used to light cities before the discovery of natural gas and the use of electricity. The fossil fuel fractions of interest, CO_2 and H_2, are separated before combustion. In the first stage, the fuel reacts with pure oxygen or water vapor ($H_2O(g)$) to produce the gas known as syngas, which consists mainly of carbon monoxide (CO) and hydrogen (H_2). The syngas is converted into CO_2 (which is captured) and H_2, which can be a source of energy production without CO_2 being released into the atmosphere, as the combustion of H_2 only produces heat and water vapor ($H_2O(g)$) (Figure 8) [23-26].

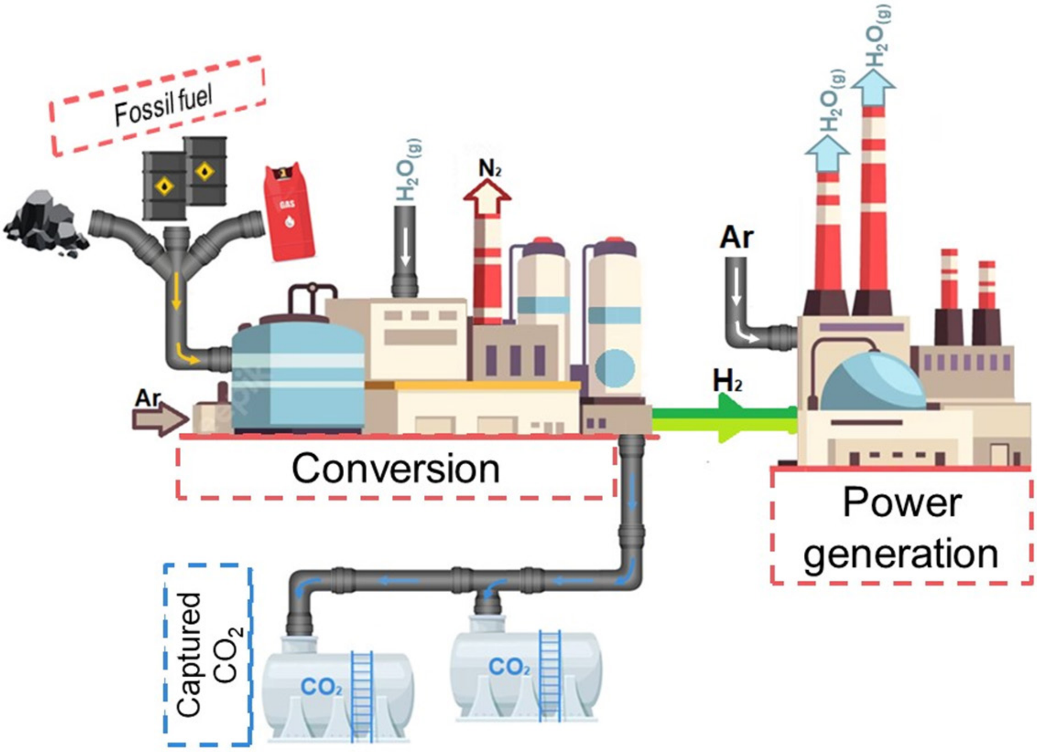


Figure 8: Simplified pre-combustion flowchart.

Oxygen combustion

This method was first proposed in the 1980s in order to achieve a greater concentration of CO2 in the combustion gas and thus facilitate its purification for advanced oil production. As the name suggests, combustion takes place in an atmosphere enriched with oxygen (O_2) [27,28]. In this process, pure oxygen, oxygen-enriched air or oxygen that has been separated from the air in an air separation plant is supplied for combustion. By carrying out the combustion using only oxygen instead of air (consisting of ± 78.1% N2; 20.9% O_2, 0.9% air, 0.03% CO_2 [15], the exhaust gas produced consists mainly of water vapor (H_2Og) and CO_2 with a high concentration (between 80-98%, depending on the fuel used), which is an advantage of this process (Figure 9). Combustion with pure oxygen produces a flame with an excessively high temperature (≈ 3500 oC), but the products of this combustion can be fed back into the burner, thereby controlling this temperature [22,26].

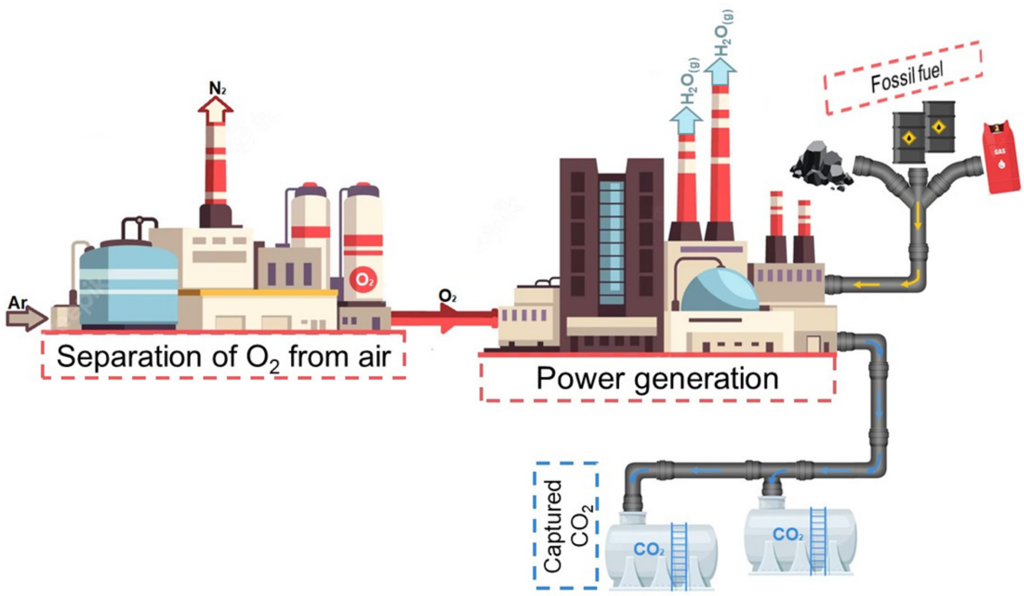


Figure 9: Simplified flowchart of combustion with oxygen.

Post combustion

Post-combustion systems separate the CO_2 produced after combustion instead of releasing it directly into the atmosphere. Fossil fuels are used to generate energy. The combustion gasses, a mixture of CO_2, nitrogen (N_2) and some oxygen-containing compounds (SOx, NOx, O_2), are first treated to remove suspended solids and oxides of nitrogen and sulfur and then capture the CO_2 (Figure 10) [22,24,29]. Among the CO_2 capture technologies, post-combustion CO_2 capture (PCC) is considered the most promising process, as it is already commercially available, has proven successful in the oil and gas industry and can be adapted to or implemented in existing industrial plants. The challenges of this process are the low concentration and low partial pressure of CO_2 in the flue gas, which reduces capture efficiency and increases energy requirements, as well as the energy required to capture other gaseous pollutants from the flue gasses [30,31]. Several methods are used for PCC, with membrane separation, absorption and adsorption being the most important. Figure 11 summarizes some of the post-combustion CO_2 capture processes [23,32].

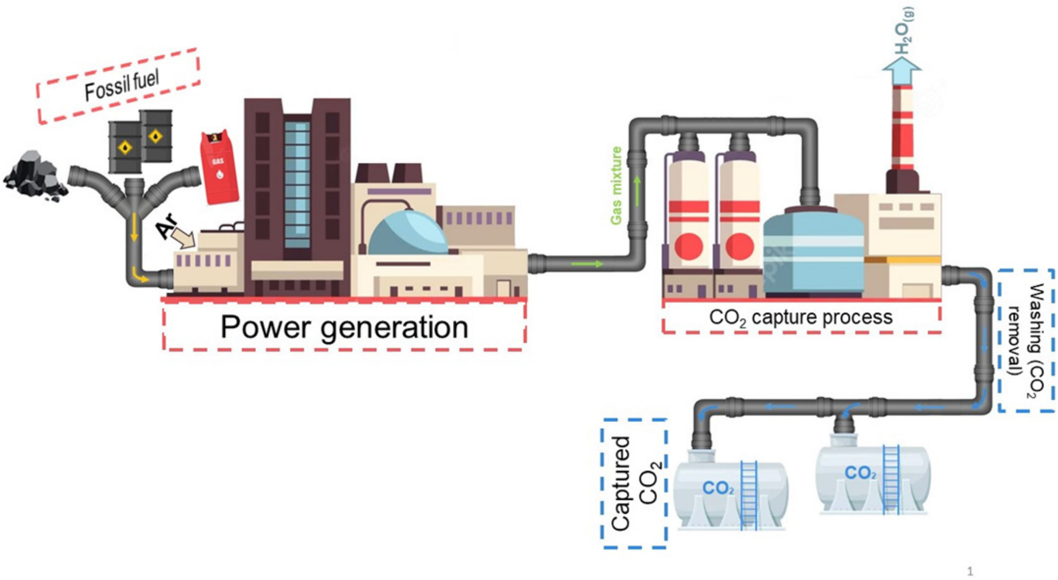


Figure 10: Simplified post-combustion flowchart.

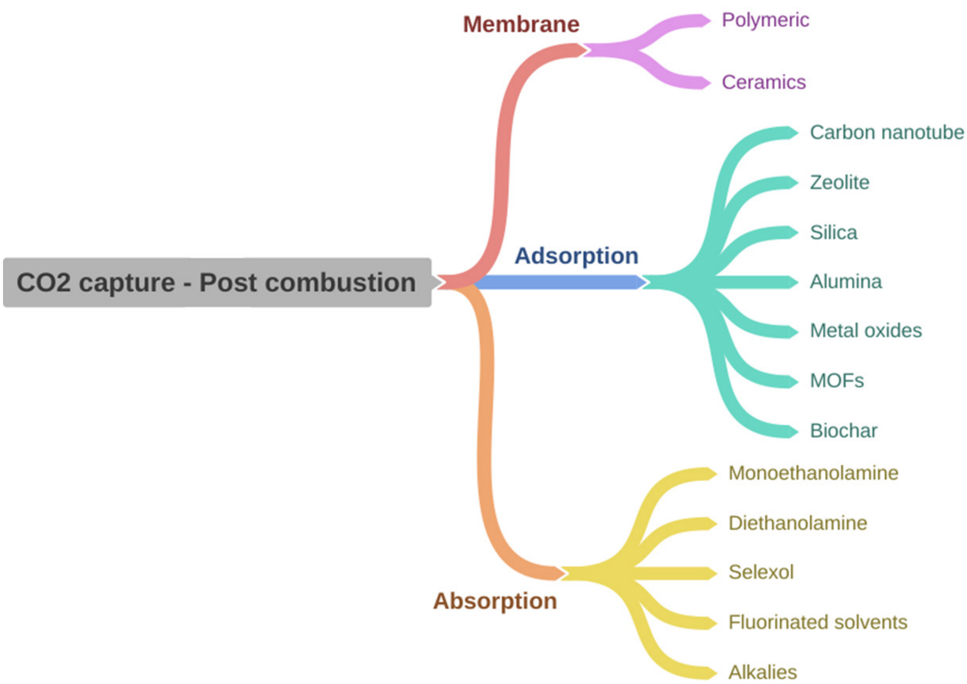


Figure 11: Different technologies used for PCC.

Conclusion

In conclusion, based on the data analyzed and the discussion presented, it is clear how urgently measures are needed to control and reduce greenhouse gas emissions [33-36]. Consequently, it is necessary to take a closer look at CO_2 removal techniques and consolidate those with the best cost-benefit ratio, both in financial and environmental terms. Integrated systems for capturing pollutants within emission sources are proving to be one of the main viable solutions to mitigate the effects of air pollution.

Conflict of interest

The authors declare that there is no conflict of interest.

References

1. Feng J, Paynter D, Menzel R (2023) How a stable greenhouse effect on earth is maintained under global warming. Journal of Geophysical Research: Atmospheres 128(9): 1-19.
2. Abhinandan K, Pardeep S, Pankaj R, Chaudhery MH (2022) Impact of COVID-19 on greenhouse gases emissions: A critical review. Sci Total Environ 806: 150349.
3. Jun P, Gillenwater M, Barbour W (2023) CO_2, CH_4, and N_2O emissions from transportation-water-borne navigation.
4. Shukla PR (2022) IPCC climate change 2022-Mitigation of climate change working group III.
5. Julio ES, Rui PPLR, Paulo JC, José PBM, João MMA, et al. (2019) Absorption of fluorinated greenhouse gases using fluorinated ionic liquids. Industrial and Engineering Chemistry Research 58(45): 20769-20778.
6. EPA (2023) Overview of greenhouse gases. US.
7. EU (2023) Fluorinated greenhouse gases.
8. Signor D, Cerri, CEP (2013) Nitrous oxide emissions in agricultural soils: a review. Pesquisa Agropecuária Tropical 43(3): 322-338.
9. Gilberto CD, Bruna SM, Cássio MS, Nelson L, Rejane HRC (2022) Assessment of nitrous oxide and carbon dioxide emissions and the carbon footprint in an aerobic granular sludge reactor treating domestic wastewater. Environmental Engineering Science 39(6): 561-572.
10. Claudia RM, Pedro APP, Wilson ALJB (2003) Global carbon, nitrogen and sulfur cycles. New Chemistry at School 5: 28-41.
11. Jean R, Ahmed G, Robert P, Joseph G (2018) NOx reduction using a dual-stage catalyst system with intercooling in vehicle gasoline engines under real driving conditions. SAE International Journal of Engines 11(6): 893-901.
12. IEA (2022) CO_2 Emissions in 2022.
13. Kathleen AM, Charlotte U, Ludmila W, Tim Butler (2022) Beyond CO_2 equivalence: The impacts of methane on climate, ecosystems, and health. Environmental Science and Policy 134: 127-136.
14. Kabir M, Habiba U, Iqbal MZ, Shafiq M, Farooqi ZR, et al (2023) Impacts of anthropogenic activities & climate change resulting from increasing concentration of Carbon dioxide on environment in 21st Century: A critical review. Earth and Environmental Science 1194: 1-6.
15. Mohamadou D, Bernard L, Eric R, Andreas E, Juan AA (2017) Global distribution of CO_2 in the upper troposphere and stratosphere. Atmospheric Chemistry and Physics 17(6): 3861-3878.
16. Gasparovic CLM (2022) Constructive design of CO_2 capture systems from post-combustion gases through mineralization.
17. IPCC (2023) Climate change 2023 synthesis report.
18. Wong M (2012) Thermodynamics of the Earth's atmosphere. Young Scientists Journal 5(11): 23.
19. IPCC (2007) Climate change 2007: The physical science basis. US.
20. Yoro KO, Daramola MO (2020) CO_2 emission sources, greenhouse gases, and the global warming effect. Advances in Carbon Capture pp. 3-28.
21. Xuan PN, Anh TH, Icon, Aykut IO, Thanh TH (2021) Record decline in global CO_2 emissions prompted by COVID-19 pandemic and its implications on future climate change policies. Energy Sources, Part A: Recovery, Utilization and Environmental Effects.
22. IPCC (2023) Special report on carbon dioxide capture and storage.
23. Olajumobi A, Lei W, Weiguo X, Richard D, Malek A (2022) Post-combustion CO_2 capture via a variety of temperature ranges and material adsorption process: A review. J Environ Manage 313: 115026.
24. Bandilla KW (2020) Carbon capture and storage in future energy: improved, sustainable and clean options for our planet. pp. 669-692.
25. Lu Lu, Jeremy SG, Catherine AP, Xiuping Z, Greg H, et al. (2018) Rau wastewater treatment for carbon capture and utilization. Nature Sustainability 1: 750-758.
26. Elhenawy SEM, Khraisheh M, Almomani F, Walker G (2020) Metal-organic frameworks as a platform for CO_2 capture and chemical processes: Adsorption, membrane separation, catalytic-conversion, and electrochemical reduction of CO_2. Catalysts 10(11): 1293.
27. Chen G, Shiyuan L, Linwei W (2023) Current investigation status of oxy-fuel circulating fluidized bed combustion. Fuel 342: 127699.
28. Chuguang Z, Zhaohui L, Jun X, Liqi Z, Shihong Z, et al. (2015) Fundamental and technical challenges for a compatible design scheme of oxyfuel combustion technology. Engineering 1(1): 139-149.
29. Podder J, Patra BR, Pattnaik, F, Nanda S, Dalai AK (2023) A review of carbon capture and valorization technologies. Energies 16(6): 2589.
30. Alalaiwat D, Khan E (2023) Current status and future scenarios of carbon capture from power plants emission: A review. Reviews in Environmental Science and Bio/Technology 22: 799-822.
31. Ateke H, Idaereesoari A, Victor J (2023) Formulation and modification of multi-walled carbon nanotubes for post-combustion CO_2 Capture. International Journal of Energy Engineering 13(1): 13-23.
32. Ekanayaka SS, Ruvishani LS, Jinasoma PND, Piyathilaka KMSN, Pathirana NMH (2020) Review of post-combustion carbon dioxide capture technologies. Journal of research technology and engineering 1(4): 44-50.
33. Josep GC, Pedro MS (2021) Global carbon and other biogeochemical cycles and feedbacks. pp. 673-816.
34. Fung I (2023) Carbon cycle. in: encyclopedia of physical science and technology. pp. 417-429.
35. Ian Cameron (2015) Blast furnace ironmaking. pp. 677-678.
36. IEA (2023) Methane and climate change-Global methane tracker 2022.

