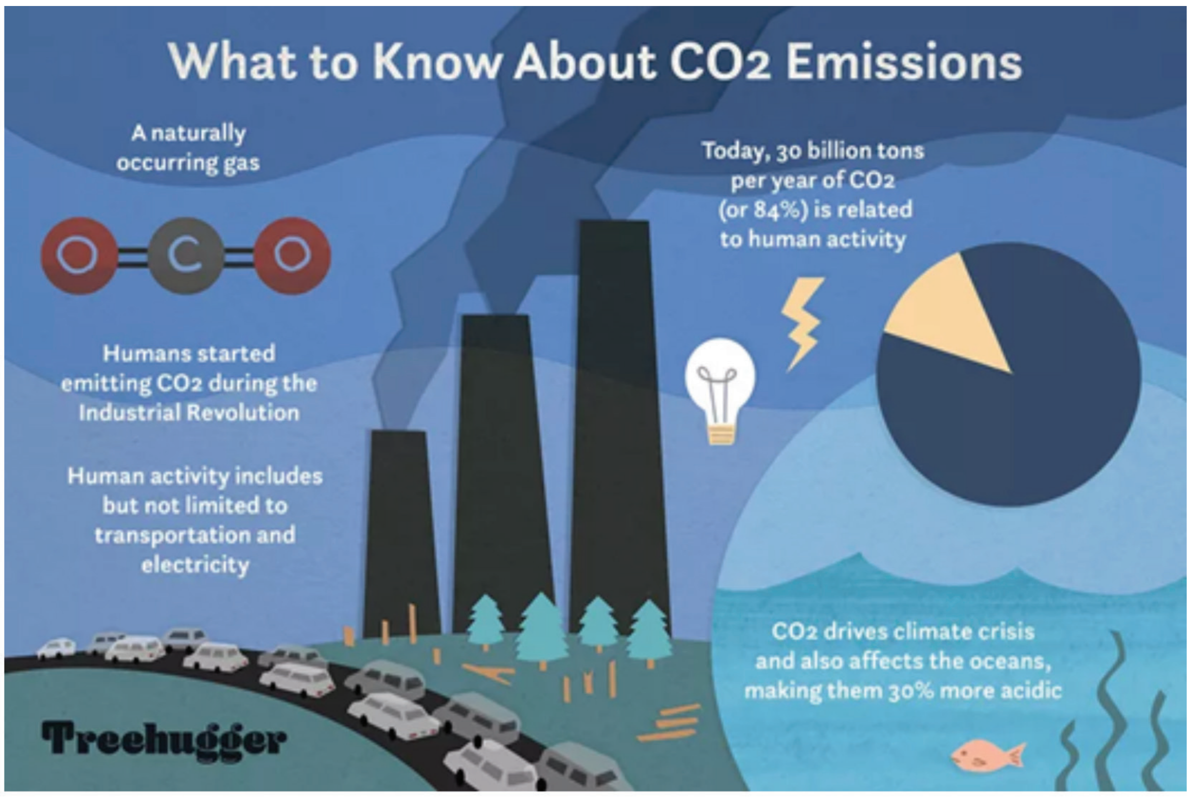
THE PROSPECTIVE APPROACHES TO LIMIT GLOBAL CARBON EMISSIONS AND THE ADVERSE EFFECTS OF GASEOUS CO_2

Rapidly increasing CO_2 gas emissions generated from human activity is one of the world's leading environmental concerns because of its negative impact on the environment, ranging from water to air pollution, global warming, and biodiversity deterioration. Consequently, many people are seeking ways to protect the environment. The use of alternative energy sources to generate electricity, instead of burning fossil fuels, showcases a positive change in the industry to pursue an environmentally conscious yet economic mindset. The primary modern sources of alternative energy are wind, solar, and nuclear energy. Shifts in the industry, driven by strict environmental regulations on carbon emissions, are resulting in the decreased use of fossil fuels. Also, new methods and materials have been developed to lessen and capture industrially produced CO_2. Many scientists and engineers are also working to limit CO_2 emissions by either decreasing the consumption of fossil fuels, using less energy, or improving the efficiency of energy production. In this paper, we will be discussing the latest ways on how to decrease, capture, and measure CO_2 emissions and the importance of regulating carbon emissions.

CO_2 can either be captured through physical or chemical means. Bioenergy capturing carbon and storage (BECCS) is representative of a physical process. BECCS involves extracting bioenergy from biomass and then using this energy to separate CO_2 into carbon and oxygen. This carbon is subsequently captured and stored to prevent its direct release into the atmosphere. Through chemical means, CO_2 can be decomposed into carbon monoxide and oxygen, though the decomposition reaction must be driven by supplied energy. There is a diverse set of methods to physically remove CO_2, chemically break it down, and ultimately store it. These methods range from improved agricultural practices, optimized decomposition reactions for CO_2, advanced instrumentation, conversion of gaseous carbon into solid carbon, and using large bodies of water to serve as carbon storage sites. There are many carbon capture, utilization, and storage technologies that need to be tested at global and international scales, in order to satisfy increasingly stringent emissions regulations and energy goals. In addition, a variety of instruments exist to measure CO_2 in the environment. Gauging CO_2 levels is essential for identifying of areas that are producing an excess of CO_2, which would consequently require the implementation of regulations to limit these emissions. Additionally, maintaining optimal levels of CO_2 helps to optimize plant yield, growth conditions for specimens, and work environments. New test methods and instrumentation are constantly being developed in response to growing interest in global environmental preservation.



Human activity generates about 84% of total excess CO_2 gas emissions, ranging from using light energy to burning fossil fuels [1].

Effects of CO_2 emissions on the environment and industry

Since the Industrial Revolution, CO_2 emissions have been rapidly increasing each year due to increased fossil fuel consumption and energy demands. Today, about 84% of CO_2 gas emissions are attributed to the burning of fossil fuels for transportation and electricity generation. Also, increased CO_2 levels are a driving factor for climate crises and ocean acidification, resulting in oceans being 30% more acidic on average [1].

Power plants that burn fossil fuels, like coal, oil, and natural gas, are the main contributors to rising CO_2 emissions. Although fossil fuels are our primary source of energy today, burning them causes many problems, which necessitates the discovery of new and more sustainable alternatives, like biofuels, nuclear energy, and solar energy.

Power plants are industrial facilities that generate electric power through the combustion of fossil fuels and are responsible for releasing the largest quantities of CO_2 into the atmosphere, comparatively to any other human activity [2].

There are many negative effects CO_2 can have on the environment. The major consequences are global warming and flooding induced by rising ocean levels. As global warming increases, we are experiencing less snowfall and more flooding in coastal and low elevated areas. Another consequence is biodiversity deterioration, meaning that more species are becoming extinct due to habitat destruction, caused by increasing temperatures or rising sea levels. In addition, as CO_2 gas levels rise globally, the acidity of oceans continues to increase [3]. For terrestrial animals, the inhalation of excess quantities of CO_2 can easily cause respiratory problems. Also, increased CO_2 levels can cause the occurrence of acid rain, which can negatively affect natural vegetation and corrode buildings and infrastructure. Due to these harmful effects, switching to alternative energy sources has been a primary objective in the industry.

The most viable alternatives to burning fossil fuels for energy revolve around the harnessing of wind, solar, and nuclear energy. Wind energy currently contributes to 7% of the US's electricity production and is a clean, abundant, and renewable source of energy [4]. There have been recent developments in wind turbine components, primarily for pitch control technologies and bearings. Pitch control systems are vital for controlling blade spins and preventing strong winds from uncontrollably rotating these blades [5]. Meanwhile, bearings reduce the overall weight, size, and manufacturing costs of wind turbines. Additionally, they can bear thrust loads, providing optimal and normal performance during harsh weather conditions and high wind speeds [5]. Also, solar energy has been on the rise, with more solar panel installations and increasing conversion rates of heat to electrical energy. Experts predict that the largest impacts on the energy sector will result from developments in solar technology. "Floatovoltaics" are solar power systems created for floating on bodies of water, offering greater efficiency and more space for solar energy production without using valuable real estate [6].

The water below keeps the solar panels clean and minimizes energy waste. This image was taken in California, Napa Valley [6].

Additionally, building-integrated photovoltaics (BIPV) enables people to save on building material and electricity costs. BIPV also offers benefits including increased energy efficiency, high thermal and sound insulation, and zero carbon footprint [6]. In addition to this, solar fabrics, which incorporate solar panels in each fiber, are being developed by researchers. These solar filaments in clothing help keep people warm, power phones, and help save on solar power mounting and costs [6]. Researchers estimate that overall solar energy will increase by 600% from 2020 to 2050 [4]. Nuclear energy, which involves the generation of heat for use in steam turbines to produce electricity, is currently looking like the best alternative to fossil fuels. Nuclear energy operates at much higher capacity factors than conventional renewable energy sources and fossil fuels, resulting in more efficient energy displaced and leading to safer environments with more available fresh water, food, and shelter. Additionally, two new innovations, fuel cells, and small, single-cycle gas turbines offer an immense advantage over large, centralized power plants, with both experiencing increasing popularity in the industry. These local generations are fueled by natural gas, which can both reduce transmission losses and improve air quality [4]. Many researchers also state that if these new innovations can be adopted in vehicles, emissions from small gas turbines and fuels will plummet as a result [4].

Latest Methods of decreasing, containing, and measuring CO_2

Currently, there are many methods for reducing global carbon emissions. Using better engine oils and replacing old, worn-out engines with newer and more energy-efficient ones can help limit total emissions. For example, substituting conventional light bulbs with LEDs, can increase energy efficient and preserve energy expenditure [7]. Moreover, in 2016, China substituted cars with bikes for transportation by 10% due to traffic issues and growing air pollution [8]. Also, new cars have been made to decrease excess CO_2 emissions, like the electric vehicles (EVs) manufactured by Tesla. Tesla states that their EVs can save up to 600 more pounds of CO_2 per year compared to the average amount of CO_2 emitted by conventional petroleum-powered vehicles [9]. Also, in 2019, scientists have developed a new method that involves the collection of gaseous CO_2 and its subsequent conversion into a useful organic polymer. [10]. Using X-rays, researchers found that the coordination polymer (PCP) structure rearranges as CO_2 molecules come to it, so that the CO_2 can be trapped. Once the material has accumulated enough CO_2, it is able to be reused as an organic polymer, which is primary used in clothing or for packaging. This newly developed method does not expend too much energy while suctioning out CO_2 from the air. By using this PCP containing zinc ions, CO_2 can be attracted to the zinc with "10 times the efficiency of other PCPs (with other elements)" [10]. This PCP is also reusable and durable, meaning that it can function at the same speed for up to ten reaction cycles.

Furthermore, there have been technological developments and changes in the automotive industry, with the main ones being innovations that can decrease carbon dioxide gas emissions significantly [11]. These include a triple-junction solar module sunroof with an efficiency of 31.17%, the world's highest conversion efficiency of 26.33% achieved in a crystalline silicon solar cell, a water splitting-biosynthetic system with CO_2 reduction efficiencies exceeding photosynthesis, and the world's tallest wind turbine integrated with pumped storage hydro. The sunroof has the highest photovoltaic conversion efficiency and can be an alternative to burning fossil fuels. The new world record for thin-film solar cells is a project that has achieved the highest PV conversion efficiency in a thin-film solar cell, and with the advantage of them having a low cost, they should significantly reduce greenhouse gas (GHG) emissions [11]. The world's highest conversion efficiency achieved in a crystalline silicon solar cell is 26.33% and is anticipated to lead to the more widespread use of PV power generation in residences with little installation space. The water-splitting biosynthetic system has a solar energy conversion efficiency of 10% or can capture 1/10 of the energy from sunlight and turn it into fuel [11]. The tallest wind turbine integrated with pumped storage hydro is the first major wind turbine to put water in its turbine to generate its power and has a big possibility of contributing to future wind power penetration. In additional, American multinational oil and gas corporation, ExxonMobil, is currently projecting that CO_2 levels will decrease by as much as 20% by 2025. ExxonMobil is planning to invest in newly developed/efficient carbon-capturing machines, while placing greater significance on maximizing energy efficient and minimizing production waste.

Carbon capturing is a process that involves the removal of excess CO_2 from the air, which is then either stored underground, in concrete, or in the soil, so that it does not enter the atmosphere immediately [13]. There are five primary ways to store or break down CO_2 in the atmosphere. By managing and restoring forests, photosynthesis can decrease the levels of CO_2 in the atmosphere, which has the added benefit of being relatively inexpensive compared to other methods. Another effective way is to use more agricultural soil for carbon storage instead of limiting more than 900 million acres of land solely for agricultural purposes. Although the quantity of carbon that agricultural soil is able to store is finite, the crops grown on the soil additionally contribute to lessening CO_2 emissions. Also, environmentalists found that putting carbon in soil can increase the health of the soil and the plants that grow on it, while installing trees can help shade and forage livestock [14]. A third and currently risky way to store CO_2 is through the process of BECCS. For example, in Switzerland, the world's first commercial plant (The Climateworks AG) for capturing CO_2 at an industrial scale directly from the air was built. The developers estimate that 900 tons of CO_2 will be captured annually and that creating 250,000 more copies would capture the equivalent amount of CO_2 released by most cars in the world [15]. This process uses biomass for energy to capture emitted gases, before storing it underground or in long-lived substances, like concrete [14]. However, since BECCS relies on bioenergy from crops, BECCS could displace food production or natural ecosystems, erasing climate benefits and exacerbating food insecurity and ecosystem loss. Carbon mineralization is another option for combating carbon emissions. Mineralizing carbon or converting gaseous carbon into solid carbon naturally takes more than a hundred years, but scientists are now figuring out ways to allow these minerals, naturally occurring silicate rocks, to encounter CO_2 in the water or air in order to accelerate the process. Also, by injecting CO_2 into rocks, CO_2 can be stored manually. The fifth and final way is by using ocean-based concepts. Instead of solely using the land for carbon capture, the large bodies of water can also serve as a place for carbon storage. However, these ocean-based solutions are in their early stages of development and still need additional testing to validate their efficacy. Improper implementation of this method can result in the deaths of many aquatic organisms from CO_2 inhalation. Besides this, each approach to these concepts aims to speed up carbon cycles in waters, capitalize on photosynthesis in coastal plants, and add minerals to increase the storage of carbon dioxide [14].

In addition to capturing CO_2, there are multiple ways of measuring CO_2 levels and pollution. Measurements are typically taken using a wide range of meters and sensors, with gases being measured in parts per million (ppm). The safe range of CO_2 is typically measured to be between 250-400ppm, outdoors, and 400-900ppm, indoors. Furthermore, maintaining optimal levels of CO_2 optimizes plant yield, growth, or chambers for biological samples and specimens, while in colder climates, it saves energy and improves the work quality inside schools, hospitals, and businesses.

Table showing the safe levels of CO_2 measured in ppm on land [16]:

250-400ppm	Normal background concentration in outdoor ambient air
400-1,000ppm	Concentrations typical of occupied indoor spaces with good air exchange
1,000-2,000ppm	Complaints of drowsiness and poor air.
2,000-5,000 ppm	Headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate, and slight nausea may also be present.
5,000	Workplace exposure limit (as 8-hour TWA) in most jurisdictions.
>40,000 ppm	Exposure may lead to serious oxygen deprivation resulting in permanent brain damage, coma, even death.

CO_2 levels can be determined using non-dispersive infrared light (NDIR) sensors and various CO_2 meters. An NDIR has a detector, measuring the amount of infrared wavelength that is absorbed by the surrounding air and with this measurement, the concentration in ppm of a specific gas is calculated [17]. The key components of NDIR sensors are an infrared source, a light tube, an interference (wavelength) filter, and an infrared detector. It functions through the diffusion of a gas into the light tube, while the electronics measure the absorption of the light.

Infrared lights are beamed into a tube with two openings for letting gas particles in and out, has a filter so when gas particles hit the filter the wavelength of light is absorbed goes to a detector which measures the concentration of any specific gas, in this case, CO_2 [18].

Optimizing the CO_2 levels of interior spaces, greenhouses, and incubators allow for greater production. Facilities, such as offices, hospitals, and schools have automated systems that control CO_2 levels, which increases air quality and saves energy in colder climates [19]. In greenhouses, it is integral to maintain CO_2 levels at around 400 ppm to optimize yield [19]. CO_2 incubators for biological specimens, which uphold elevated CO_2 levels, are critical for cultivating cells and ensuring the optimal growth of the specimens [19].

Discussion and Conclusion

As CO_2 levels continue to rise, environmental concerns, such as global warming and ozone deterioration, are becoming increasingly important to address. As a result, there have been new environmental regulations implemented to restrict GHG emissions. In June 2019, the US Environmental Protection Agency (EPA) issued regulations regarding emissions from fossil fuel-fired power plants, as stated in the Affordable Clean Energy Rule (ACE) [20]. ACE establishes emission guidelines for the coal-fired power plants in each state and identifies the best system of emissions reduction for CO_2 that can be implemented at individual facilities. By 2030, the ACE rule is projected to reduce CO_2 emissions by 11 million tons from 2019 [20]. In 2018, the EPA proposed regulations for restricting the amount of GHG emissions in new, changed, and rebuilt power plants. These proposed regulations would set emission rate performances for reconstructed power plants to be equivalent to that of newly constructed units which normally have emission rates close to 2,200 lbs. CO_2/MWh. This rule would also make quality and refined emission reduction systems that are equal to or equivalent to supercritical steam generators (coal power plants). They have emission rates of "1.900 lbs. CO_2/MWh and would set the best system of emission reducwtions for small units to 2,000 lbs. CO_2/MWh" [21].

Additionally, professions related to environmental safety are forecasted to increase worldwide. ExxonMobil predicts that CO_2 emissions can be reduced by 15% in four years by taking measures like continual investments in products that create lower emissions; increased support and strictness of sound and public policies regarding CO_2 emissions and increased cogeneration capacity at manufacturing facilities [12]. But, by not taking measures like these and not considering technological improvements, the US Energy Information Administration (EIA) predicts that after 2030, energy usage will increase—predominantly in transportation and industrial—and will cause CO_2 emissions to increase [22]. However, they also project that by 2050, the US will have 4% less CO_2 in the atmosphere than in 2019 [22]. So, researchers and energy administrators are not sure what will happen in the future with excess CO_2 levels going down due to more people using more fuels to generate energy and electricity. But jobs are projected to grow, according to the Bureau of Investigation, by 3% between 2018 and 2028 about the average growth rate of all occupations [23]. As CO_2 emissions increase yearly, more meters and sensors will need to be installed in third world countries and other areas that produce significant GHG emissions. After measuring CO_2 concentrations in these areas, capturing, and storing CO_2 can become a crucial step to reduce emissions to a regulated level.

References

[1] Platt, John. "CO_2 101: Why Is Carbon Dioxide Bad?" TreeHugger, 23 Sept. 2020

[2] staff, Science X. "Burning Fossil Fuels Poses Existential Threat to Earth." Phys.org, Phys.org, 27 Oct. 2016 **FYI:// Isn't within 2 years because its a picture reference

[3] "The Carbon Cycle." NASA, NASA, 16 June 2011 //This isn't within 2 years but it contains information that hasn't changed till this day

[4] "Renewable Energy." Center for Climate and Energy Solutions, Center for Climate and Energy Solutions, 27 Apr. 2020\

[5] Froese, Michelle, and Michelle Froese. "New Advances in Wind-Turbine Components." Windpower Engineering & Development, 7 Jan. 2019

[6] Sandhu, Jagpreet. "Which New Solar Panel Technologies Will Revolutionize Energy Production?" Solar Reviews, 8 Dec. 2020

[7] Impulse, Solar. "Solutions to the Energy Crisis: How to Achieve Sustainable Energy?" Hero Banner, Solar Impulse Foundation, 2020

[8] "Why Bicycles Are Making a Huge Comeback in China." Knowledge@Wharton, University of Pennsylvania, 30 Mar. 2017

[9] Evatran. "Tesla Drivers Have Saved Over 340 Million Pounds CO_2." Plugless Power, Mia Yamauchi, 2020

[10] David, Nield. "Scientists Create a Material That Captures CO_2 And Turns It Into Organic Matter." ScienceAlert, ScienceAlert, 15 Oct. 2019

[11] Staff, Foresight. "Top 10 Innovations That Will Help the World to Cut CO_2 Emissions." Foresight, Foresight, 29 June 2018

[12] "ExxonMobil Announces Emission Reduction Plans; Expects to Meet 2020 Goals."ExxonMobil, ExxonMobil, 14 Dec. 2020

[13] Mohammed, Malek. "Progress on Carbon Dioxide Capture, Storage, and Utilisation." Shibboleth Authentication Request, INTERSCIENCE ENTERPRISES LTD, 2020

[14] Mulligan, James, et al. "6 Ways to Remove Carbon Pollution from the Sky." World Resources Institute, World Resources Institute, 14 Oct. 2020

[15] Christa Marshall, E&E NewsJun. 1, et al. "In Switzerland, a Giant New Machine Is Sucking Carbon Directly from the Air." Science, American Association for the Advancement of Science, 8 Dec. 2017

[16] "What Are Safe Levels of CO and CO_2 in Rooms?" Kane International Limited, Kane International Limited, 2020

[17] "How Is Air Quality Measured?" NOAA SciJinks – All About Weather, SciJinks, 15 Dec. 2020

[18] "How Does an NDIR CO_2 Sensor Work?" CO_2 Meter, 13 Jan. 2020

[19] Lehto, Juhani. "Why Is Measuring CO_2 Important?" Vaisala, Vaisala, Oct. 2018

[20] "EPA Finalizes Affordable Clean Energy Rule, Ensuring Reliable, Diversified Energy Resources While Protecting Our Environment." EPA, Environmental Protection Agency, 28 July 2020

[21] "Regulating Power Sector Carbon Emissions." Center for Climate and Energy Solutions, Center for Climate and Energy Solutions, 5 Jan. 2021

[22]"U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." Outlook for Future Emissions - U.S. Energy Information Administration (EIA), US Energy Information Administration, 6 Feb. 2020

[23] "Environmental Engineers: Occupational Outlook Handbook." U.S. Bureau of Labor Statistics, U.S. Bureau of Labor Statistics, 1 Sept. 2020

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https://www.petro-online.com/news/fuel-for-thought/13/koehler-instrument-company/dr-raj-shah-director-at-koehler-instrument-company-conferred-with-multifarious-accolades/53404

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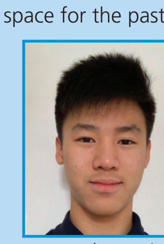
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