SASTA OLIPHANT SCIENCE AWARDS

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Science Writing

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Macey Badcock

Caritas College

What is the effect of anthropogenic carbon dioxide emissions on global warming and society? How can ocean alkalinity enhancement reduce these effects?

Earth naturally maintains thermal balance, with equal ingoing and outgoing thermal energy. Greenhouse gases, such as carbon dioxide, trap thermal energy at Earth's surface, supporting suitable temperatures for life to exist *(CSIRO, 2024).* However, when greenhouse gas concentrations increase, due to anthropogenic activities with the industrialisation of modern society, energy is not able to adequately escape. This causes thermal imbalance and is known as the enhanced greenhouse effect *(Daziani, M., Fryer, K., Tulip, S., 2025).* This phenomenon leads to global warming, where Earth's average surface temperature rises overtime at increased rates due to human impacts. The consequences of global warming, such as rising sea levels, and the harmful influence this has on society must be considered. The application of scientific knowledge on carbon dioxide exchange between the ocean and the atmosphere can be utilised in carbon dioxide removal technology. Ocean alkalinity enhancement is one such technology with the possibility to store excess atmospheric carbon dioxide in the ocean. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is currently researching OAE by unpacking its limitations and advantages *(CSIRO, 2025).*

Ideally, Earth will maintain thermal balance, when the amount of incoming and outgoing energy is in equilibrium. Greenhouse gases in the troposphere, such as carbon dioxide, methane, and nitrous oxide contribute to maintaining this balance through the greenhouse effect. Radiation emitted by the sun enters the atmosphere, where it is either absorbed or reradiated by the Earth's surface. Re-radiated energy returns to the troposphere, where it either directly exits back to space, or is absorbed and re-radiated further by greenhouse gases. This energy can be directed to another greenhouse gas molecule or the Earth's surface *(Daziani, M., Fryer, K., Tulip, S., 2025)*. Figure 1 visualises this process, showing the various directions thermal energy travels. The greenhouse effect traps heat at Earth's surface, maintaining a temperature that is comfortable for life to exist on Earth. Without greenhouse gases, Earth's average temperature would be about -18°C, which is much lower than today's average temperature of about 14°C *(CSIRO, 2024).* Complications arise from anthropogenic activity causing atmospheric concentrations of greenhouse gases, such as carbon dioxide, to increase significantly, leading to thermal imbalance. The enhanced greenhouse effect has caused more outgoing infrared radiation to be absorbed by greenhouse gases and reradiated back to the surface, preventing heat from being able to escape. This causes thermal imbalance and results in Earth's average temperature rising. This is known as global warming.

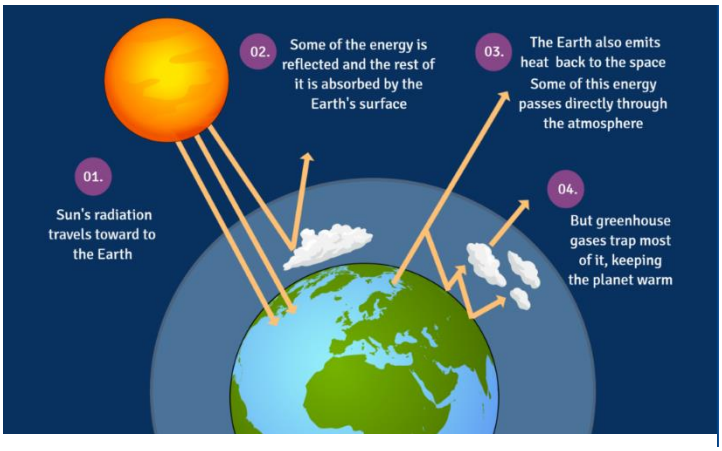

Figure 1: The Greenhouse Effect (Soares, F., 2019).

Greenhouse gases tend to contain three or more atoms and can emit infrared radiation. One such greenhouse gas is carbon dioxide. Carbon dioxide's chemical formula is CO_2, meaning one molecule is made up of a carbon atom and two oxygen atoms, bonded by double covalent bonds. Carbon dioxide exchange between the ocean and the atmosphere is in equilibrium, with the ocean absorbing almost 30% of anthropogenic carbon dioxide emissions *(Shadwick, E., Rohr, T., Richardson, A., 2023)*. Carbon dioxide from the atmosphere dissolves in water, forming carbonic acid (see reaction 1).

Reaction 1: $CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)}$, *carbon dioxide dissolving in water.*

The carbonic acid undergoes a 2-stage ionisation reaction in the water. This is a chemical process where a neutral species gains or loses electrons, resulting in the formation of ions *(Britannica, 2016)*. In the first stage, hydrogen carbonate ions and a hydronium ion are formed (see reaction 2).

Reaction 2: $H_2CO_{3(aq)} + H_20_{(l)} \rightarrow HCO_3^-{}_{(aq)} + H_3O^+_{(aq)}$, *stage 1 of ionisation.*

In the second stage, hydrogen carbonate ions will react with water, producing carbonate ions and hydronium ions (see reaction 3).

Reaction 3: $HCO_3^-{}_{(aq)} + H_2O_{(l)} \rightarrow CO_3^{2-}{}_{(aq)} + H_3O^+_{(aq)}$, *stage 2 of ionisation.*

When atmospheric carbon dioxide levels are high, oceans will have increased numbers of hydronium ions present. This causes pH to decrease, as pH is dependent on the concentration of hydronium ions in the species.

Industrialised society has become reliant on the burning of fossil fuels, combustion engines in transportation, and electricity production, all of which have led to the increased concentration of atmospheric carbon dioxide *(CO_2 Human Emissions, 2017).* Figure 2 demonstrates a rapid increase in carbon dioxide emissions from 1950 through to 2023, increasing by approximately 32.5 billion tonnes in this time *(Our world in Data, 2024).* Human carbon dioxide emissions are less than 5% of total emissions, with the remaining residing with natural sources such as aerobic respiration, volcanic eruptions, and decomposition of organisms *(Daziani, M., Fryer, K., Tulip, S., 2025)*. The natural intake of carbon dioxide through photosynthesis, ocean absorption, and soil sequestration is equal to the natural output. However, with the addition of anthropogenic emissions, the natural balance of the

carbon cycle which has existed for thousands of years prior to human influence has been disrupted *(Moseman, A., 2024)*.

The scientific community accepts that "increases in greenhouse gases due to human activities have been the dominant cause of observed global warming," *(CSIRO, 2024)*. With greater concentrations of greenhouse gases in the atmosphere, more heat is trapped at the Earth's surface. Since Australian records began in 1910, the average temperature has increased by 1.51 ± 0.23°C *(Australian Bureau of Meteorology, 2024)*. While this may not appear to be a significant increase, the consequential impacts of this rise in temperature are evident.

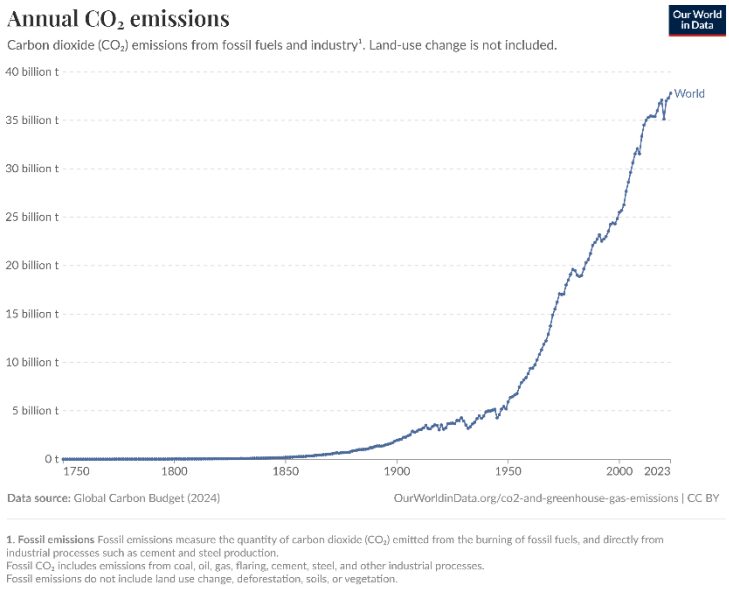

Figure 2: The increase of anthropogenic CO_2 emissions from 1750 to 2023 (Our World in Data, 2024).

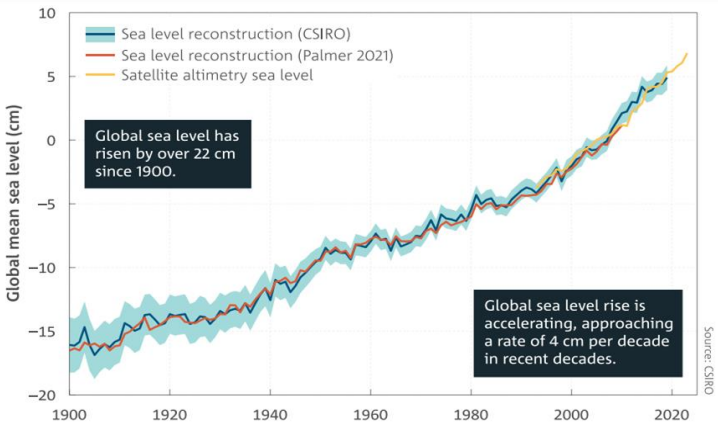

Figure 3: The global mean sea level across time (Australian Bureau of Meteorology, 2024).

One consequence of global warming is rising sea levels. Seawater undergoes thermal expansion, occupying larger volumes, when heated by energy reradiated by greenhouse gases, including carbon dioxide. Melting of land and sea ice due to rising temperatures also contributes as ice melts and enters the oceans. The State of the Climate 2024 reports a 22 cm increase in global mean sea levels since 1900. Figure 3 illustrates this increase, particularly showing its acceleration, as sea levels are increasing at a faster rate in recent decades. This puts coastal communities at risk of floods, erosion and saltwater intrusion, causing these areas to become uninhabitable, leading to mass displacement of people *(Australian Bureau of Meteorology, 2024)*. Furthermore, economic impacts must be considered. Increased costs for protection measures such as sea walls, surge barriers, and repairing damaged infrastructure will be influenced by rising sea levels. One -billion people globally are affected by rising sea levels, highlighting the need for these effects to be addressed *(Masterson, V., Hall, S., North, M., 2025)*. Many other consequences of global warming include increased likelihood of extreme weather events, melting of permafrost, biodiversity loss, and ecosystem stress.

The impacts of anthropogenic greenhouse gas emissions encourage research and new technologies to be investigated. With carbon dioxide being the most abundant greenhouse gas, reducing its concentration is crucial. OAE is one solution in consideration. Scientific knowledge of how carbon

dioxide exchanges between the atmosphere and the ocean has provided the basis for OAE. Alkalinity is added to waters naturally over thousands of years as limestone and basalt rocks weather, dissolving into the ocean. By increasing alkalinity, ocean carbon dioxide partial pressure decreases, causing equilibrium to be lost. To reestablish equilibrium, the ocean increases its uptake of carbon dioxide. *(CSIRO, 2025).* When carbon dioxide is dissolved, it dissociates and is stored in the ocean for extended periods of time (see reaction 2 and 3), reducing atmospheric carbon dioxide concentration. Research is underway by a CSIRO research team, led by Dr Elizabeth Shadwick. By applying naturally occurring processes, but accelerating the rate at which they occur, has the potential to reduce the amount of carbon dioxide in the atmosphere. The research team explores electrochemical approaches to OAE, where seawater is split into basic and acidic components. Then, the basic components are added back to the ocean, increasing alkalinity, and therefore carbon dioxide uptake.

Societal ideations of leaving the ocean uninfluenced may lead to this approach being rejected by the wider community. However, Shadwick stated, “the problem has become so much more urgent … we need to do net removal as well,” as relying only on the reduction of emissions will not be enough to reduce carbon dioxide’s effects. It is Shadwick’s hope that “the need for action outweighs the reluctance to tinker,” (*CSIRO, 2024)*. However, CSIRO acknowledges that there are limitations in knowledge of the short-term risks associated with OAE on marine life. The intent of their research is to ensure that OAE can be ethical and safe. Institute for Marine and Antarctic Studies researcher, Professor Lennart Bach, suggested limitations of this technique. Alkalinity enhancement would increase the population of the phytoplankton coccolithophores. Shifting carbonate equilibrium would benefit this species, with increased calcification involved with their calcium carbonate shells reducing OAE efficiency by 2-29% by 2100 *(University of Tasmania, 2025)*. This finding shows that large-scale feedback systems in the ocean must be considered when evaluating OAE efficiency. Furthermore, a project of this scale will inevitably require investors. A legal framework to merge financial and ethical responsibilities should be produced for future implementation of OAE to ensure practices are safe, ethical, and receive adequate support *(Akhand, A., 2024)*.

OAE opens possible avenues reducing the atmospheric carbon dioxide concentration, helping to minimise the detrimental influence global warming has on society, from rising sea levels to extreme weather events, and many more. A limitation of this solution is that it is still in early development, with uncertainties in the risks it provokes to sea life, and how efficient the process will be. CSIRO actively continues their research to extend their knowledge on OAE limitations.

Anthropogenic carbon dioxide emissions enhance global warming by preventing thermal energy from emitting back to space, causing temperatures on Earth to increase. One consequence of global warming is rising sea levels, influencing coastal communities by putting them at risk of floods, erosion and mass displacement. These harmful impacts, among many others, has produced demands to find solutions which capture and store carbon dioxide from the atmosphere. OAE is a technology that is still early in development, but has the possibility to achieve this goal, reducing the effect anthropogenic carbon dioxide emissions have on society and Earth.

SHE Research Task

Word Count: 1476

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