# Anthropogenic CO2 Sources and Sinks

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The primary sources of anthropogenic $CO_2$ are emissions from burning fossil fuels and cement production, which are responsible for an estimated 75% of the increase in atmospheric $CO_2$ concentrations since pre-industrial times (IPCC 2007, p.512)[1]. Changes in land use and land conversion are also considered a significant source of $CO_2$. This includes practices like deforestation which cause a loss of plant biomass as well as various agricultural practices such as fertilization and irrigation, leading to an increase in soil carbon in agricultural land. Other changes in land use management that contribute to $CO_2$ emission include biomass burning, crop production and conversion of grasslands to croplands. (IPCC 2007, p.511) Not only do these practices emit $CO_2$, but they also reduce the land's capacity to act as a carbon sink. "Land use responds to social and economic pressures to provide food… Land clearing can lead to soil degradation, erosion and leaching of nutrients, and may therefore reduce the subsequent ability of the ecosystem to act as a carbon sink" (IPCC 2001, p.193)[2]

However, "observed increase in atmospheric $CO_2$ concentrations does not reveal the full extent of human emissions in that it accounts for only 55% of the $CO_2$ released by human activity since 1959. The rest has been taken up by plants on land and by the oceans" (IPCC 2007, p.512). This represents the Earth's main natural sinks; the ocean, which represents the largest natural carbon sink on Earth, and photosynthesis, which converts $CO_2$ into organic compounds both on land and underwater.

$CO_2$'s solubility is inversely correlated with sea water temperature. When it reacts with water, it is broken down into dissolved inorganic carbon (DIC), which includes $CO_2$, bicarbonate ($HCO_3^-$), and carbonate ($CO_3^{2-}$) ions. As cold water is heavily enriched with DIC, it sinks to the deeper ocean. This is further driven by the meridional overturning circulation (MOC), which moves sea water in accordance with differential density gradients. "This localized sinking, associated with the MOC is termed the *solubility pump*", and is considered a major driver of anthropogenic $CO_2$ entering the ocean (IPCC 2007, p.514).

Photosynthesis removes $CO_2$ from the atmosphere as it converts it into organic compounds (mainly sugars) using solar energy. In the ocean, phytoplankton takes up carbon through photosynthesis, some of which "sinks from the surface layer as dead organisms and particles". This is known as the *biological pump*, which acts together with the solubility pump to regulate $CO_2$ exchange

[1] Denman, K.L., Brasseur, G. et al. (2007). *Couplings Between Changes in the Climate System and Biogeochemistry*. Intergovernmental Panel on Climate Change (IPCC).
[2] Prentice, I.C. et al. (2001). *The Carbon Cycle and Atmospheric Carbon Dioxide*. Intergovernmental Panel on Climate Change (IPCC).

between the ocean and the atmosphere by maintaining a vertical $CO_2$ gradient (IPCC 2007, p.514).

On a much larger time-scale, $CO_2$ is removed from the atmosphere "though weathering by silicate rocks and through burial in marine sediments of carbon fixed by marine plants" (IPCC 2007, p.511).

Fires can act as both a carbon source and sink. Fire's role as a source is considered relatively short-term, but it can add to "a small longer-term sink through production of slowly decomposing and inert black carbon". On a larger scale, its role remains somewhat in question as there is evidence that increased fire frequency, specifically in Canada is related to climate change. "Flannigan et al. (2005) estimate that in the future, the $CO_2$ source from fire will increase" (IPCC 2007, p.527).

Indeed, there are many possible changes these sources and sinks may experience in the future. Potential factors include climate change, changes in humankind's $CO_2$ producing activities, as well as changes to land management policies and practices.

With respect to agricultural conversion of natural vegetation to agriculture, IPCC (1996b) estimated that appropriate management practices could increase carbon sinks by 0.4 to 0.9 PgC/yr (IPCC 2001, p.194). "Ecosystem conservation and management practices can restore, maintain and enlarge carbon stocks (IPCC, 2000a)".

The ocean's role as a sink may be influenced by several factors. One possibility is decreased effectiveness of the solubility pump due to rising ocean temperatures, which would lower the ocean's DIC capacity. It has also been noted that $CO_2$ uptake has lowered the ocean's pH by approximately 0.1 since 1750 (IPCC 2007, p.533). This may reduce calcification by shell-forming organisms, thus disrupting the biological pump. Furthermore, rising $CO_2$ concentration will hinder seawater buffering capacity and potentially slow down circulation, thereby stifling oceanic uptake of anthropogenic $CO_2$ (IPCC 2007, p. 533).

While the particulars remain uncertain, the most important control of 21$^{st}$ century atmospheric $CO_2$ concentrations will likely be the amount to which humankind can reduce emissions. Higher atmospheric and oceanic $CO_2$ concentrations trigger a positive feedback effect which results in decreased capacity or effectiveness of the Earth's natural carbon sinks. Therefore, the only option is to take social, political and economic measures to reduce $CO_2$ emissions. While changes in land use and land management may help increase terrestrial carbon sinks, ultimately this is not a long-term solution. The ocean's dominant role in the carbon cycle coupled with its projected reduced sink capacity would ensure that atmospheric $CO_2$ concentrations would continue to rise.