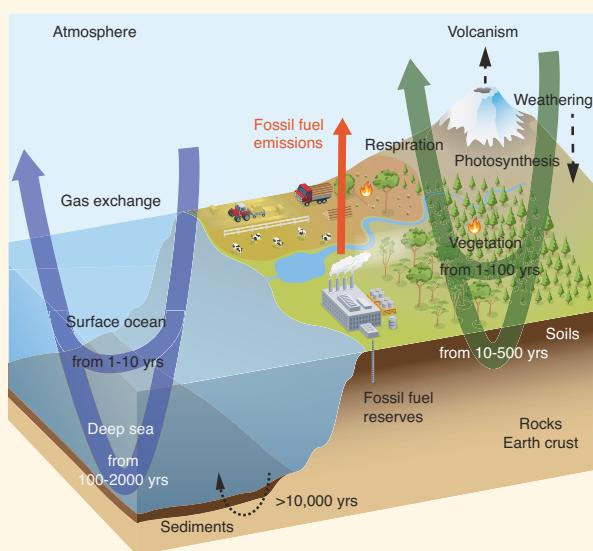


Frequently Asked Questions

FAQ 6.2 | What Happens to Carbon Dioxide After It Is Emitted into the Atmosphere?

Carbon dioxide (CO_2), after it is emitted into the atmosphere, is firstly rapidly distributed between atmosphere, the upper ocean and vegetation. Subsequently, the carbon continues to be moved between the different reservoirs of the global carbon cycle, such as soils, the deeper ocean and rocks. Some of these exchanges occur very slowly. Depending on the amount of CO_2 released, between 15% and 40% will remain in the atmosphere for up to 2000 years, after which a new balance is established between the atmosphere, the land biosphere and the ocean. Geological processes will take anywhere from tens to hundreds of thousands of years—perhaps longer—to redistribute the carbon further among the geological reservoirs. Higher atmospheric CO_2 concentrations, and associated climate impacts of present emissions, will, therefore, persist for a very long time into the future.

CO_2 is a largely non-reactive gas, which is rapidly mixed throughout the entire troposphere in less than a year. Unlike reactive chemical compounds in the atmosphere that are removed and broken down by sink processes, such as methane, carbon is instead redistributed among the different reservoirs of the global carbon cycle and ultimately recycled back to the atmosphere on a multitude of time scales. FAQ 6.2, Figure 1 shows a simplified diagram of the global carbon cycle. The open arrows indicate typical timeframes for carbon atoms to be transferred through the different reservoirs.



FAQ 6.2, Figure 1 | Simplified schematic of the global carbon cycle showing the typical turnover time scales for carbon transfers through the major reservoirs.

sinking dense waters transport the carbon between the surface and deeper layers of the ocean. The marine biota also redistribute carbon: marine organisms grow organic tissue and calcareous shells in surface waters, which, after their death, sink to deeper waters, where they are returned to the dissolved inorganic carbon reservoir by dissolution and microbial decomposition. A small fraction reaches the sea floor, and is incorporated into the sediments.

The extra carbon from anthropogenic emissions has the effect of increasing the atmospheric partial pressure of CO_2 , which in turn increases the air-to-sea exchange of CO_2 molecules. In the surface ocean, the carbonate chemistry quickly accommodates that extra CO_2 . As a result, shallow surface ocean waters reach balance with the atmosphere within 1 or 2 years. Movement of the carbon from the surface into the middle depths and deeper waters takes longer—between decades and many centuries. On still longer time scales, acidification by the invading CO_2 dissolves carbonate sediments on the sea floor, which further enhances ocean uptake. However, current understanding suggests that, unless substantial ocean circulation changes occur, plankton growth remains roughly unchanged because it is limited mostly by environmental factors, such as nutrients and light, and not by the availability of inorganic carbon it does not contribute significantly to the ocean uptake of anthropogenic CO_2 . (continued on next page)

Before the Industrial Era, the global carbon cycle was roughly balanced. This can be inferred from ice core measurements, which show a near constant atmospheric concentration of CO_2 over the last several thousand years prior to the Industrial Era. Anthropogenic emissions of carbon dioxide into the atmosphere, however, have disturbed that equilibrium. As global CO_2 concentrations rise, the exchange processes between CO_2 and the surface ocean and vegetation are altered, as are subsequent exchanges within and among the carbon reservoirs on land, in the ocean and eventually, the Earth crust. In this way, the added carbon is redistributed by the global carbon cycle, until the exchanges of carbon between the different carbon reservoirs have reached a new, approximate balance.

Over the ocean, CO_2 molecules pass through the air-sea interface by gas exchange. In seawater, CO_2 interacts with water molecules to form carbonic acid, which reacts very quickly with the large reservoir of dissolved inorganic carbon—bicarbonate and carbonate ions—in the ocean. Currents and the formation of

FAQ 6.2 (continued)

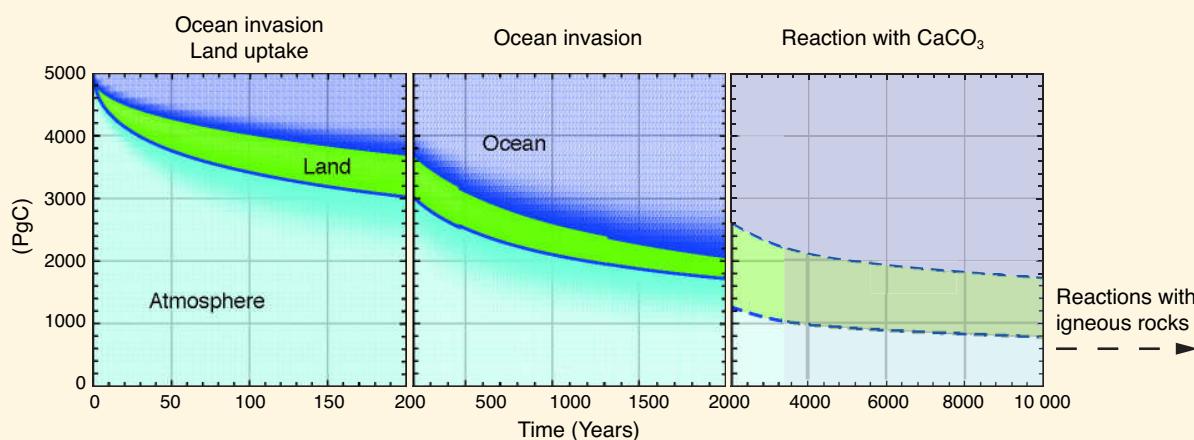
On land, vegetation absorbs CO₂ by photosynthesis and converts it into organic matter. A fraction of this carbon is immediately returned to the atmosphere as CO₂ by plant respiration. Plants use the remainder for growth. Dead plant material is incorporated into soils, eventually to be decomposed by microorganisms and then respiration back into the atmosphere as CO₂. In addition, carbon in vegetation and soils is also converted back into CO₂ by fires, insects, herbivores, as well as by harvest of plants and subsequent consumption by livestock or humans. Some organic carbon is furthermore carried into the ocean by streams and rivers.

An increase in atmospheric CO₂ stimulates photosynthesis, and thus carbon uptake. In addition, elevated CO₂ concentrations help plants in dry areas to use ground water more efficiently. This in turn increases the biomass in vegetation and soils and so fosters a carbon sink on land. The magnitude of this sink, however, also depends critically on other factors, such as water and nutrient availability.

Coupled carbon-cycle climate models indicate that less carbon is taken up by the ocean and land as the climate warms constituting a positive climate feedback. Many different factors contribute to this effect: warmer seawater, for instance, has a lower CO₂ solubility, so altered chemical carbon reactions result in less oceanic uptake of excess atmospheric CO₂. On land, higher temperatures foster longer seasonal growth periods in temperate and higher latitudes, but also faster respiration of soil carbon.

The time it takes to reach a new carbon distribution balance depends on the transfer times of carbon through the different reservoirs, and takes place over a multitude of time scales. Carbon is first exchanged among the 'fast' carbon reservoirs, such as the atmosphere, surface ocean, land vegetation and soils, over time scales up to a few thousand years. Over longer time scales, very slow secondary geological processes—dissolution of carbonate sediments and sediment burial into the Earth's crust—become important.

FAQ 6.2, Figure 2 illustrates the decay of a large excess amount of CO₂ (5000 PgC, or about 10 times the cumulative CO₂ emitted so far since the beginning of the industrial Era) emitted into the atmosphere, and how it is redistributed among land and the ocean over time. During the first 200 years, the ocean and land take up similar amounts of carbon. On longer time scales, the ocean uptake dominates mainly because of its larger reservoir size (~38,000 PgC) as compared to land (~4000 PgC) and atmosphere (589 PgC prior to the Industrial Era). Because of ocean chemistry the size of the initial input is important: higher emissions imply that a larger fraction of CO₂ will remain in the atmosphere. After 2000 years, the atmosphere will still contain between 15% and 40% of those initial CO₂ emissions. A further reduction by carbonate sediment dissolution, and reactions with igneous rocks, such as silicate weathering and sediment burial, will take anything from tens to hundreds of thousands of years, or even longer.



FAQ 6.2, Figure 2 | Decay of a CO₂ excess amount of 5000 PgC emitted at time zero into the atmosphere, and its subsequent redistribution into land and ocean as a function of time, computed by coupled carbon-cycle climate models. The sizes of the colour bands indicate the carbon uptake by the respective reservoir. The first two panels show the multi-model mean from a model intercomparison project (Joos et al., 2013). The last panel shows the longer term redistribution including ocean dissolution of carbonaceous sediments as computed with an Earth System Model of Intermediate Complexity (after Archer et al., 2009b).