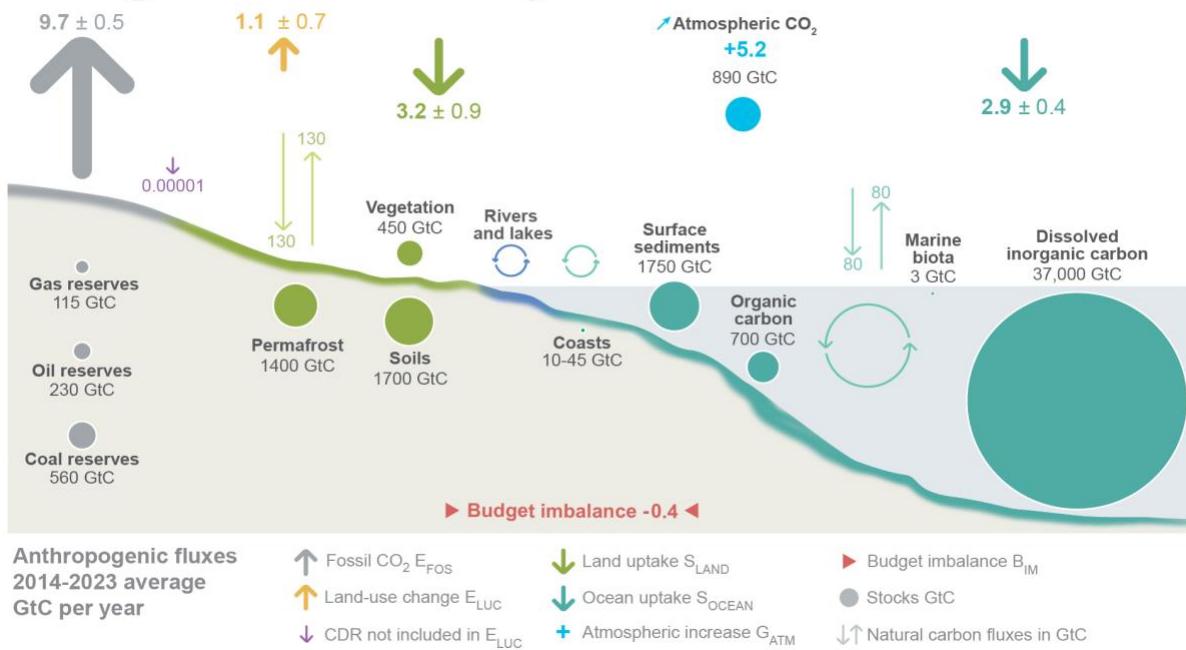


First, some basics. Most of Earth's carbon is stored in rocks and the rest is in the ocean, atmosphere, plants, soil, and fossil fuels. Flows of carbon from reservoir to reservoir make up the carbon cycle, which has fast and slow components.[1]

Photosynthesizing plants and plankton capture and accumulate CO₂ from the atmosphere and pass it up the food chain to other life forms. Respiration by organisms and eventual death and decay return CO₂ to the air or into soil. Carbon moves through this biological cycle in years to decades.[2]

The slow or rock cycle involves carbon in the air falling in rain, rock weathering, and erosion with sediment and organic debris flowing into the ocean. Carbon from these sources and carbon dissolved from the air can be made into shells. Shells and sediment slowly sink to the bottom of the ocean and cement into limestone rock. This is how 80% of carbon-containing rock is made. The rest comes from living things buried in mud, compressed by heat and pressure, to form coal, oil and methane gas. Carbon returns to the air through volcanic activity.[2] Geochemical processes take hundreds to millions of years.[1]

The global carbon cycle



Source: Friedlingstein et al, Global Carbon Budget 2024, Figure 2 [3]

In this diagram of what the carbon cycle looks like currently, stores of carbon appear as shaded circles and arrows show carbon movement between reservoirs, as average annual fluxes for the past decade 2014-2023.[3] A lot of carbon cycles into and out of the atmosphere naturally, 130 gigatonnes of carbon per year (GtC/yr) from land and 80 from the ocean. Human activities generate emissions of 10.8 GtC/yr, 9.7 from fossil fuels and 1.1 from land-use change such as clearing forest for farmland.[4] After land and vegetation absorb 3.2 and the ocean 2.9 GtC/yr, there is still 5.2 GtC/yr added to the atmosphere, with a small “budget imbalance” for methodology variances and unknowns. Global warming is tied to atmospheric CO₂; in this context, carbon sources or emitters add carbon to the air, while carbon sinks absorb or remove carbon from the atmosphere.

This is just a snapshot. Fluxes and reservoirs are not constant, and are altered by human activities and global warming.[5] Different parts of the carbon cycle respond in different ways and at different rates. The fast carbon cycle is evident in the CO₂ fertilization effect, when increased CO₂ spurs plant growth and CO₂ capture through photosynthesis. This may be boosted by longer growing seasons, but is limited by water and nutrient availability. Deforestation by humans reduces the land sink, while planting new forests or allowing forests to regenerate adds to it. Natural disturbances such as drought, insects and disease, and fires, exacerbated by climate change, weaken the land sink. Thawing turns permafrost soil from carbon reserve to carbon source. The net effect of these complex interactions is tough to calculate, because there is so much variation in landscapes, in plant and soil composition, and in how global warming manifests locally.[6,7] Tallies of human land-use change are sometimes inconsistent.[8,9]

The ocean is also a major carbon sink. More carbon dissolves into the ocean as atmospheric CO₂ increases. An unfortunate consequence is acidification that harms shell-building organisms such as coral. The ocean, however, will absorb less carbon as ocean temperatures rise and chemical buffering capacity wanes.[6] The movement of carbon into surface and deeper layers of the ocean is affected by too many other factors to enumerate here.[10]

The natural carbon cycle maintained an equilibrium for some 10,000 years.[11] We are mucking up the natural carbon cycle by releasing fossil carbon on human rather than geologic timescales, exceeding its capacity to maintain equilibrium in meaningful timeframes.[12,13] Roughly half of all man-made emissions have been absorbed by natural sinks so far. What comes next? Terrestrial and ocean sinks are projected to take up more carbon, but the fraction of emissions that is absorbed will decline.[6]

Carbon is not “bad;” it is the stuff of life. Land plants and ocean are not just carbon sinks; they are life-supporting ecosystems. But fossil emissions are out of whack with the natural carbon cycle, and ruinous. You know what I’m going to say next. The fix is to retire fossil fuels and preserve our natural world.

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[13] Bralower T & Bice D. Overview of the carbon cycle from a systems perspective. Part of *Earth in the Future.* (<https://www.e-education.psu.edu/earth103/node/1019>) Residence time (average time spent in reservoir) and response time (how long to return to a steady state).