

Anthropogenic CO₂

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Synonyms

Anthropogenic carbon dioxide; Human-generated carbon dioxide

Definition

Carbon dioxide, generated by human activities, that enters the natural carbon cycle (usually through the atmosphere).

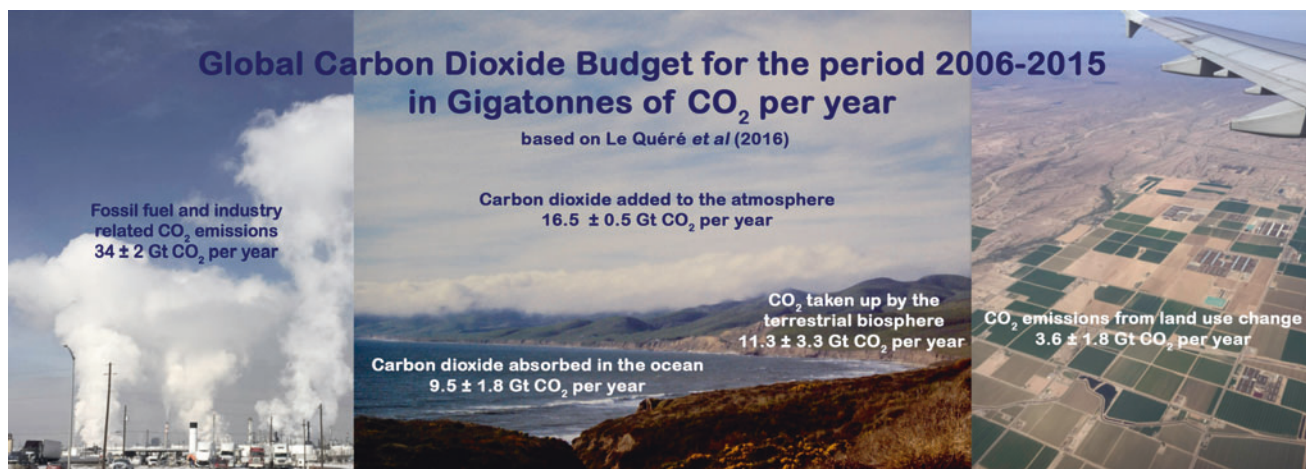
Anthropogenic carbon dioxide, chemical formula CO₂, is produced in the chemical conversion of various carbon bearing compounds or by releasing CO₂ from geological reservoirs that without human interference would have remained isolated from the more mobile carbon pools in the atmosphere, the ocean, and the biosphere.

Sources of Anthropogenic CO₂

Generation of anthropogenic CO₂ began with the introduction of fire and the combustion of biomass, which mainly produces CO₂ and H₂O. Until the industrial revolution, anthropogenic CO₂ production remained small compared to the natural

carbon cycle and was essentially balanced by the uptake of CO₂ by plants. For biomass to be burned, it first has to grow. The carbon balance was more seriously upset with the introduction of coal as an important heating fuel in Britain in the late eighteenth century at the dawn of the industrial revolution (Christianson 2000). Coal consumption grew rapidly during the nineteenth century. Prior to the industrial revolution, the occasional use of coal and oil that spontaneously comes to the surface was insignificant. By contrast, the industrialization of Britain was based on large-scale consumption of coal, and coal energy became a major foundation of modern societies. Initially, coal simply replaced wood for heating, but then took a role in powering the steam engines (Newcomb's first steam engine) (Christianson 2000) driving the pumps that kept coalmines dry. As steam engines improved, their uses spread to many different applications revolutionizing modern societies. Add to this the invention of modern steel making with coke produced from coal, and the combustion of coal released so much CO₂ to the atmosphere that it became an important and additive player in the overall carbon cycle. The rate of anthropogenic CO₂ generation accelerated even more at the end of the nineteenth century with the introduction of petroleum, which is easily refined into convenient liquid fuels like gasoline, kerosene, diesel, and jet fuel. Finally, natural gas was added to the mix, and today's CO₂ emissions from fossil fuel combustion exceed 30 billion metric tons per year. Coal, oil, and gas each contributes comparable amounts (Fig. 1).

Other anthropogenic releases of CO₂ result from the calcination of carbonates, usually lime stone, mainly in the production of cement. About half of the CO₂ in cement making results from fuel combustion, the remainder is the CO₂ freed as limestone (calcium carbonate) is converted to



Anthropogenic CO₂, Fig. 1 The global carbon dioxide budget for the decade from 2006 to 2015. The budget numbers are given in Gigatonnes of carbon dioxide per year and reflect a 10 year average. The anthropogenic fuel cycle liberates carbon from fossil fuel resources and land use. The carbon, mainly in the form of carbon dioxide enters the atmosphere, and redistributes itself between the atmosphere, the ocean and the

terrestrial biosphere. Most of the CO₂ in the ocean is dissolved inorganic carbon. Most of the carbon stored in biomass is organic matter. Here the numbers are given in terms of CO₂ masses, but often they are given in terms of carbon. One ton of carbon equals 3.67 tons of CO₂. The carbon dioxide flows have been adapted from Le Quéré C et al. (2016), Global carbon budget 2016. Earth Syst Sci Data 8(2):605.)

lime (calcium oxide). The cement industry produces about 7% of all anthropogenic CO₂ emissions (calculated from data provided by van Oost 2016 and Fishedick et al. 2014).

Not all of the carbon present in oil, coal, or gas that is extracted from the ground is directly oxidized to CO₂, some is incorporated into other chemical compounds, for example, plastics, asphalt, or carbon for carbon black in tires or in carbon electrodes. Some of these carbon-based materials will persist in the environment for long times, but many will degrade over time producing CO₂ in the process; others will be combusted in waste incineration plants that again release anthropogenic CO₂.

Finally, anthropogenic sources include CO₂ from underground gas reservoirs that are either tapped for their CO₂ content or produce CO₂ as an unintended byproduct. For example, many natural gas wells contain significant amounts of CO₂ that is co-produced with methane. In most cases, the CO₂ will have to be removed from the gas before it can be distributed to customers. For example, the Sleipner Field in the North Sea operated by Statoil produces a gas that contains about 10% carbon dioxide, too much to leave it in the gas (IPCC 2005).

Adding up the total carbon mobilized by human activities (Ciais et al. 2013), including the sources mentioned above and carbon released from deforestation and land use changes, minus the uptake induced by human activities for example in reforestation, still leaves a net release of CO₂ of 33 billion tons per year, or nine billion tons of mobilized carbon. Even though this is much smaller than the natural annual flow of carbon from the atmosphere into biological reservoirs (on the order 170 billion metric tons of carbon per year), it matters because it is not matched by an opposing flow. Photosynthesis with its large uptake and release rates causes an annual fluctuation of about 6 parts per million by volume (ppm) in the atmosphere, but does not lead to a significant change in the annual average concentration. By contrast, human emissions currently raise CO₂ concentration by about 2.2 ppm per year. Since the beginning of the industrial revolution, the CO₂ concentration in the atmosphere rose from 280 to 410 ppm in May of 2017.

Environmental Concerns Over Anthropogenic CO₂ Emissions

Anthropogenic CO₂ emissions have become a large environmental concern as they represent by far the largest contribution to human-induced climate change. Excess CO₂ redistributes itself between the atmosphere, the ocean, and the biosphere. The surface ocean is in equilibrium with the atmosphere, but the deep ocean will take many centuries to adjust to changes in the atmosphere. In equilibrium, about 80% of the excess CO₂ will end up in the ocean. Roughly half

the CO₂ emitted to the atmosphere will stay there for centuries. Over tens of thousands of years, natural removal of CO₂ from the combined atmosphere/ocean/biosphere system proceeds by geochemical processes that produce mineral carbonates (Archer et al. 2009).

As a greenhouse gas in the atmosphere, CO₂ causes global warming. Dissolved as carbonic acid in the ocean, it changes the ocean pH, and with it the carbonate chemistry of the ocean, which is important to many calcifying organisms like corals. Lastly, CO₂ leads to worldwide eutrophication of bioecosystems with concomitant imbalances.

Computational models corroborate and even strengthen the simple and physical story that CO₂ emissions are cumulative and tend to pile up in the atmosphere. Models all agree (MacDougall 2015) that the warming caused by CO₂ emissions is driven by total cumulative emission and does not depend on the shape of the emission profile. Models suggest that the reduction of the greenhouse effect due to uptake of CO₂ into the ocean is compensated for by the gradual warming of the ocean. The temperature increase will stop when emissions stop, but excess temperatures will persist for about a millennium (Solomon et al. 2009). Moreover, models agree that the expected warming is simply linear in the cumulative emissions, which hints at complex feedback mechanisms because the underlying greenhouse effect is logarithmic in the CO₂ concentration.

Policy makers and climate change scientist agree that climate change needs to be kept to a manageable level. Most countries of the world including the United States, China, and European Union signed and ratified the 1992 United Nations Framework Convention on Climate Change in Rio de Janeiro that obligates all parties to prevent dangerous levels of climate change. Today, the Intergovernmental Panel on Climate Change (IPCC) discusses a 2°C rise over preindustrial global temperatures as a threshold beyond which warming poses severe risks to humans and the environment (IPCC 2014). This corresponds to about 450 ppm of CO₂ in the atmosphere, or 45 ppm above the current level. The 21st United Nations Conference of the Parties on Climate Change in Paris in 2015 resulted in an agreement that reaffirms the 2°C limit and adds that the world should be aiming for a temperature increase of no more than 1.5°C leaving very little room for additional CO₂ emissions.

Balancing the Carbon Budget

Stabilizing the CO₂ concentration in the atmosphere at any reasonable level requires balancing the anthropogenic carbon budget. This in turn means that fossil fuel combustion must either be eliminated completely by moving to nonfossil energy sources or the remaining fossil fuel consumption has to be balanced by the safe and permanent disposal of an

equivalent amount of CO₂. Renewable energy including solar and biomass or nuclear energy could replace oil, coal, and gas, which today comprise more than 80% of the world's primary energy consumption. To the extent that fossil fuels will still be used, e.g., as jet fuels in the aviation industry, disposal of an equivalent amount of CO₂ will become necessary. Disposal processes are referred to as carbon sequestration or carbon capture and storage (IPCC 2005). Carbon dioxide storage could involve the injection of CO₂ into deep underground reservoirs, where it would occupy the pore space in a manner similar to how oil and gas are naturally stable in geological reservoirs. A second option is to bind CO₂ to natural minerals that react with carbon dioxide and water to form carbonate salts or bicarbonate salts. This process is referred to as mineral sequestration (Lackner et al. 1995). Bicarbonates tend to be water-soluble and would end up in the ocean, and carbonates are often insoluble and form minerals like limestone or calcium carbonate. Such mineralization processes occur naturally and are known as geological weathering. In their natural form, they are far too slow to keep up with anthropogenic CO₂ production, but over tens or hundreds of thousands of years, they will reinstate the natural carbon balance of the system. For practical carbon dioxide storage, mineralization would need to be accelerated by many orders of magnitude. A third option, which actually was the first to be proposed (Marchetti 1977), is to put the CO₂ into the ocean, either by dissolving it in the water column or forming lakes of CO₂ at the ocean floor. However, ocean storage of CO₂, which in water turns to carbonic acid, has been criticized on environmental grounds. The capacity of the ocean to hold sufficient CO₂ for a sufficient time may not be available. At the present rate of three trillion tons per century, CO₂ production in the coming century could easily be several trillion tons. For comparison, Lake Michigan contains 5 trillion tons of water. Ocean circulation turns over the ocean in roughly 1000 years. Considering that it will take natural processes many thousands of years to eliminate the excess CO₂, a residence time in the ocean of less than a thousand years would be too short. Similar concerns over capacity and storage time have been raised about storing anthropogenic CO₂ in the standing biomass.

Before CO₂ can be stored, it must be collected or captured. In the case of biomass growth, capture is part of the natural process of photosynthesis. For other approaches to carbon sequestration, there need to be active processes to collect CO₂. The most suitable locations for capture are the big point sources of CO₂, like power plants, refineries, steel plants, and cement plants (IPCC 2005). Among these point sources, power plants tend to be bigger and in aggregate produce much more CO₂ than other point sources. Natural gas wells frequently co-produce CO₂ that needs to be sequestered. One of the largest CO₂ disposal effort is at the above-

mentioned Sleipner Gas Field in the North Sea, where the Norwegian oil company Statoil separates the CO₂ from the natural gas at the well site and injects about one million tons of CO₂ per year into a deep saline aquifer 800 m below the seafloor (Arts et al. 2008).

Point source capture could involve retrofitting existing power plants, building new power plants with more efficient and more integrated CO₂ capture. In order to truly close the anthropogenic carbon cycle, it is not sufficient to reduce emissions or capture a large fraction of the CO₂ that is produced in the combustion process, but it will be necessary to collect all of the CO₂, even that which escapes into the atmosphere. Moreover, it may become necessary to create negative emissions where CO₂ that has already been emitted is removed from the environment. Unless emissions are reduced much more rapidly than today an overshoot scenario becomes unavoidable, and some climate scientists consider it already necessary (Hansen et al. 2013).

Collection from the environment, for example directly from the atmosphere, also makes it possible to balance out emissions from sectors of the economy that do not lend themselves to point source capture, because emissions are distributed and mobile and individually small (Lackner 2014). Vehicles, ships, and airplanes may carry fuel that is converted at the point of consumption into CO₂ and H₂O. While point source capture, for example, from flue gas can go back to well-established scrubbing technologies using, for example, amine solutions to bind CO₂ that is regenerated during a heating step, capture from ambient air requires innovative approaches, which are being developed, or combust biomass, which during its growth collected CO₂ from the atmosphere, in power plants that capture their own CO₂ and permanently dispose of it.

Conclusion

In summary, human activities have profoundly altered the natural carbon cycle on Earth by converting stable carbon from deep underground into CO₂ that flows through the mobile carbon pool. This pool includes the atmosphere, the ocean, and biomass. Since natural processes for balancing the carbon cycle are too slow to prevent the accumulation of excess CO₂ in the atmosphere, options for managing anthropogenic CO₂ and balancing the world's carbon budget are being developed.

Cross-References

- [Atmospheric Evolution](#)
- [Carbon](#)
- [Carbon Cycle](#)

- Carbonate Minerals and the CO₂-Carbonic Acid System
- Earth's Atmosphere
- Natural Gas
- Ocean Biochemical Cycling and Trace Elements
- Ocean Salinity, Major Elements, and Thermohaline Circulation
- Petroleum

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Antimony

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Element Data

Antimony (Sb: atomic weight 121.76) is a silvery metalloid with common oxidation states of (−3), (+3) and (+5). Antimony has two stable isotopes: ¹²¹Sb (natural abundance of 57.36%) and ¹²³Sb (natural abundance of 42.64%).

Properties

Antimony has four allotropes, which include the blue-white metalloid, the most common allotrope of antimony, and three meta-stable allotropes, yellow, black and explosive. Antimony forms a variety of chemical compounds such as chlorides (SbCl₃), fluorides (SbF₃), oxides (Sb₂O₃ and Sb₄O₁₀) and sulfides (Sb₂S₃) (Greenwood and Earnshaw 1997; Wiberg et al. 2001).

History and Use

Antimony has found many commercial applications. Antimony trioxides (Sb₂O₃) are most often used as fire retardants in foam filled furniture, accounting for roughly 60% of its commercial production. Antimony is also used as an alloying material for lead-acid batteries, bullets, and solder (roughly 20% of commercial use). Other applications include the use of antimony sulfides and oxides in pigments, as catalysts for the production of polyethyleneterephthalate and in the production of glasses and pyrotechnics (Butterman and Carlin Jr 2003).

Antimony Minerals

Although the abundance of antimony in the Earth's crust is less than 0.5 parts per million, it forms over a hundred mineral species, many of which are sulfide minerals. In reducing environments with high sulfide concentrations, such as those found in hydrothermal ore deposits, sulfide containing minerals such as stibnite form readily (Sb₂S₃, Fig. 1). The metal ore stibnite often occurs as iridescent needles and is mined in only a few countries, with China

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