

### Frequently Asked Question 10.3

## If Emissions of Greenhouse Gases are Reduced, How Quickly do Their Concentrations in the Atmosphere Decrease?

The adjustment of greenhouse gas concentrations in the atmosphere to reductions in emissions depends on the chemical and physical processes that remove each gas from the atmosphere. Concentrations of some greenhouse gases decrease almost immediately in response to emission reduction, while others can actually continue to increase for centuries even with reduced emissions.

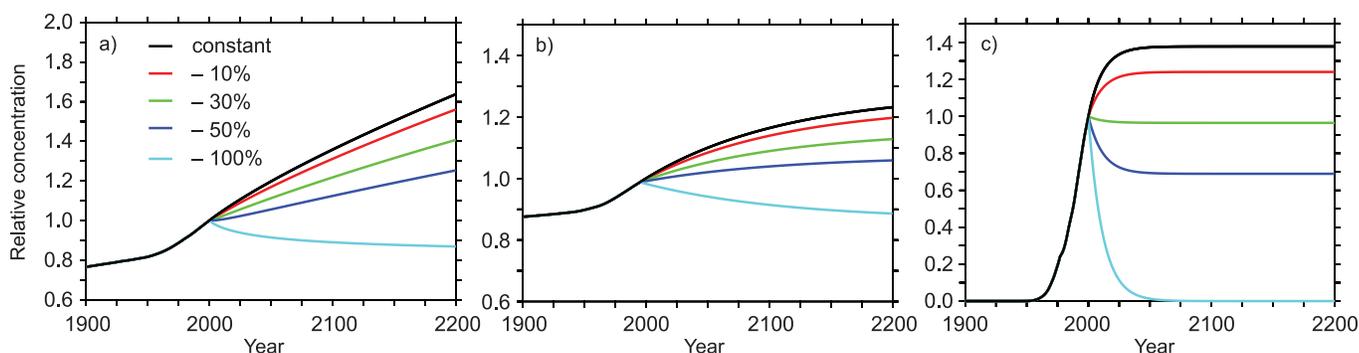
The concentration of a greenhouse gas in the atmosphere depends on the competition between the rates of emission of the gas into the atmosphere and the rates of processes that remove it from the atmosphere. For example, carbon dioxide ( $\text{CO}_2$ ) is exchanged between the atmosphere, the ocean and the land through processes such as atmosphere-ocean gas transfer and chemical (e.g., weathering) and biological (e.g., photosynthesis) processes. While more than half of the  $\text{CO}_2$  emitted is currently removed from the atmosphere within a century, some fraction (about 20%) of emitted  $\text{CO}_2$  remains in the atmosphere for many millennia. Because of slow removal processes, atmospheric  $\text{CO}_2$  will continue to increase in the long term even if its emission is substantially reduced from present levels. Methane ( $\text{CH}_4$ ) is removed by chemical processes in the atmosphere, while nitrous oxide ( $\text{N}_2\text{O}$ ) and some halocarbons are destroyed in the upper atmosphere by solar radiation. These processes each operate at different time scales ranging from years to millennia. A measure for this is the lifetime of a gas in the atmosphere, defined as the time it takes for a perturbation to be reduced to 37% of its initial amount. While for  $\text{CH}_4$ ,  $\text{N}_2\text{O}$ , and other trace gases such as hydrochlorofluorocarbon-22 (HCFC-22), a refrigerant fluid, such lifetimes can be reasonably determined (for  $\text{CH}_4$  it is about 12 yr, for  $\text{N}_2\text{O}$  about 110 yr and for HCFC-22 about 12 yr), a lifetime for  $\text{CO}_2$  cannot be defined.

The change in concentration of any trace gas depends in part on how its emissions evolve over time. If emissions increase with time, the atmospheric concentration will also increase with time, regardless of the atmospheric lifetime of the gas. However, if actions are taken to reduce the emissions, the fate of the trace gas concentration will depend on the relative changes not only of emissions but also of its removal processes. Here we show how the lifetimes and removal processes of different gases dictate the evolution of concentrations when emissions are reduced.

As examples, Figure 1 shows test cases illustrating how the future concentration of three trace gases would respond to illustrative changes in emissions (represented here as a response to an imposed pulse change in emission). We consider  $\text{CO}_2$ , which has no specific lifetime, as well as a trace gas with a well-defined long lifetime on the order of a century (e.g.,  $\text{N}_2\text{O}$ ), and a trace gas with a well-defined short lifetime on the order of decade (such as  $\text{CH}_4$ , HCFC-22 or other halocarbons). For each gas, five illustrative cases of future emissions are presented: stabilisation of emissions at present-day levels, and immediate emission reduction by 10%, 30%, 50% and 100%.

The behaviour of  $\text{CO}_2$  (Figure 1a) is completely different from the trace gases with well-defined lifetimes. Stabilisation of  $\text{CO}_2$  emissions at current levels would result in a continuous increase of atmospheric  $\text{CO}_2$  over the 21st century and beyond, whereas for a gas with a lifetime on the order of a century (Figure 1b) or a decade (Figure 1c), stabilisation of emissions at current levels would lead to a stabilisation of its concentration at a level higher than today within a couple of centuries, or decades, respectively. In fact, only in the case of essentially complete elimination of

(continued)



**Figure 1.** (a) Simulated changes in atmospheric  $\text{CO}_2$  concentration relative to the present-day for emissions stabilised at the current level (black), or at 10% (red), 30% (green), 50% (dark blue) and 100% (light blue) lower than the current level; (b) as in (a) for a trace gas with a lifetime of 120 years, driven by natural and anthropogenic fluxes; and (c) as in (a) for a trace gas with a lifetime of 12 years, driven by only anthropogenic fluxes.

emissions can the atmospheric concentration of CO<sub>2</sub> ultimately be stabilised at a constant level. All other cases of moderate CO<sub>2</sub> emission reductions show increasing concentrations because of the characteristic exchange processes associated with the cycling of carbon in the climate system.

More specifically, the rate of emission of CO<sub>2</sub> currently greatly exceeds its rate of removal, and the slow and incomplete removal implies that small to moderate reductions in its emissions would not result in stabilisation of CO<sub>2</sub> concentrations, but rather would only reduce the rate of its growth in coming decades. A 10% reduction in CO<sub>2</sub> emissions would be expected to reduce the growth rate by 10%, while a 30% reduction in emissions would similarly reduce the growth rate of atmospheric CO<sub>2</sub> concentrations by 30%. A 50% reduction would stabilise atmospheric CO<sub>2</sub>, but only for less than a decade. After that, atmospheric CO<sub>2</sub> would be expected to rise again as the land and ocean sinks decline owing to well-known chemical and biological adjustments. Complete elimination of CO<sub>2</sub> emissions is estimated to lead to a slow decrease in atmospheric CO<sub>2</sub> of about 40 ppm over the 21st century.

The situation is completely different for the trace gases with a well-defined lifetime. For the illustrative trace gas with a lifetime of the order of a century (e.g., N<sub>2</sub>O), emission reduction of more than 50% is required to stabilise the concentrations close to present-day values (Figure 1b). Constant emission leads to a stabilisation of the concentration within a few centuries.

In the case of the illustrative gas with the short lifetime, the present-day loss is around 70% of the emissions. A reduction in emissions of less than 30% would still produce a short-term increase in concentration in this case, but, in contrast to CO<sub>2</sub>, would lead to stabilisation of its concentration within a couple of decades (Figure 1c). The decrease in the level at which the concentration of such a gas would stabilise is directly proportional to the emission reduction. Thus, in this illustrative example, a reduction in emissions of this trace gas larger than 30% would be required to stabilise concentrations at levels significantly below those at present. A complete cut-off of the emissions would lead to a return to pre-industrial concentrations within less than a century for a trace gas with a lifetime of the order of a decade.

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