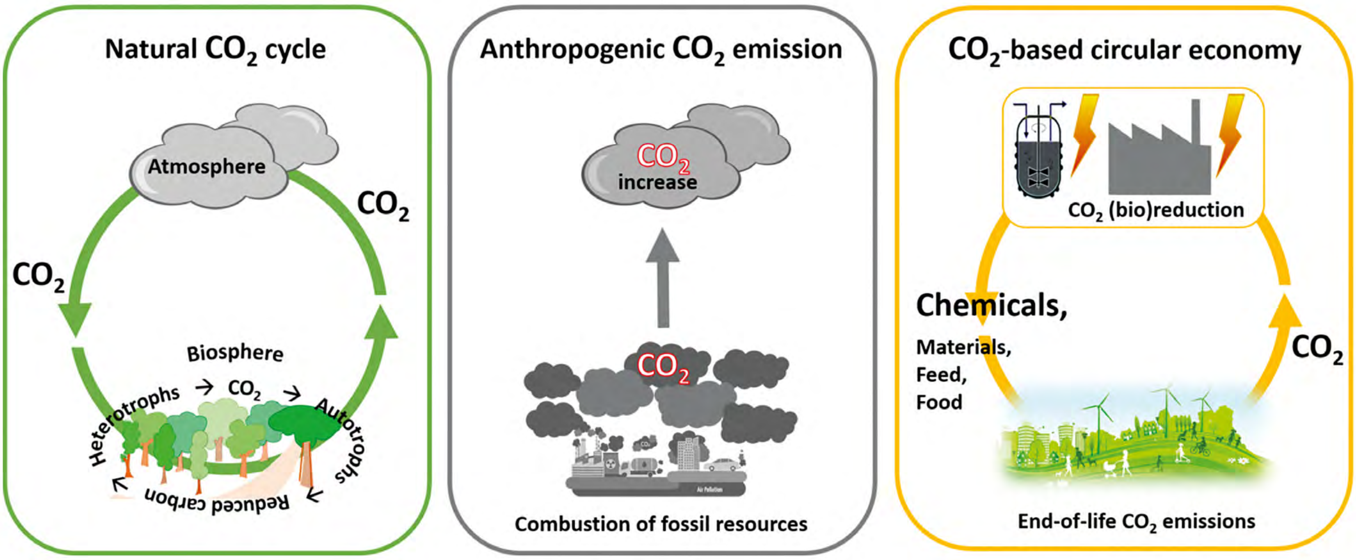
Regina Kratzer

Towards a CO_2-Based Circular Economy

Carbon dioxide is an essential component of the Earth's biosphere and as such is part of the biological carbon cycle.



The biological or fast carbon cycle describes the movement of carbon as it is recycled between the biosphere and the atmosphere. In the biosphere, CO_2 is assimilated into organic compounds by so-called autotrophs and thus forms the basis of life for all organisms that are not able to fix CO_2. These heterotrophs in turn use reduced organic compounds as building blocks and obtain energy from the oxidation of organic molecules to CO_2 (Figure 1). Human activities have resulted in a significant alteration to the natural carbon cycle. The burning of fossil carbon sources such as coal, oil and gas has caused CO_2 in the atmosphere to rise by 50% (Figure 1). One strategy for reducing CO_2 emissions into the atmosphere is to use it as carbon source for the production of chemicals, materials, animal feed and even food. By doing so, excess CO_2 is removed and a framework for a CO_2-based circular economy is formed. The prerequisites for this are (bio)chemical reduction methods of CO_2 and the availability of cheap energy sources (Figure 1). The most important chemical reduction processes are based on transition metal-catalyzed hydrogenations. However, sulphur and nitrogen compounds in CO_2-rich gases poison transition metal catalysts, limiting their lifetime. A promising approach to avoiding frequent catalyst changes is the use of self-replicating, CO_2-assimilating biocatalysts. The main classes of autotrophic microorganisms are photoautotrophs, which rely on light as an energy source, and lithoautotrophs, which derive the energy required for CO_2 assimilation from chemical reactions. Aerobic hydrogen-oxidizing bacteria (lithoautotrophic HOBs) are able to assimilate CO_2 using H_2 as electron donor with O_2 as final electron acceptor. The advantage of aerobic HOBs compared to photoautotrophs or anaerobic lithoautotrophs is that the strongly exothermic oxyhydrogen reaction provides significantly more energy for metabolic processes.

Figure 1. As a field of science that utilizes biological systems for technological applications, biotechnology seeks to use HOBs (and other autotrophic organisms) for CO_2 conversion into various products. The main obstacle to the full exploitation of HOBs is the explosiveness of the substrate gas mixture consisting of H_2, O_2 and CO_2. Although several research groups were already cultivating HOBs successfully in the second half of the last century, stricter safety regulations at the beginning of the third millennium led to a decline in this field of research. In recent years, biotechnological strategies for the assimilation of CO_2 have once again come to the fore. Under the coordination of Regina Kratzer (Institute for Biotechnology and Biochemical Engineering), several working groups at Graz University of Technology have joined forces to develop lab-scale bioreactors for the cultivation of HOBs. The centrepiece is a standard lab-scale bioreactor, which was converted for operation with explosive gases under the supervision of Markus Raiber and Vanja Subotic from the Institute of Thermal Engineering (Figure 2). The first results obtained with the bioreactor were successfully published (Bioengineering Best Paper Award) and our (then) doctoral student Vera Lambauer won the dissertation prize of the Forum for Technology and Society at TU Graz. These activities are also supported by the start-up Econutri, which operates one of the world's few ATEX-compliant bioreactors on pilot scale at TU Graz/acib. (We want to emphasize that all gas fermenters were ATEX-certified by external bodies.) Currently, the gas fermentation process is implemented in a Digital Twin to facilitate safe processing by fully automated process control. The data obtained will be utilized in the new lead project DigiBioTech in order to facilitate predictive scale-up to the cubic meter scale using machine learning enhanced computational fluid dynamics (Stefan Radl, Institute of Process and Particle Engineering). This will allow for a better assessment of the potential of HOBs in the landscape of biological and chemical possibilities for the reduction of CO_2. In this context, the author wants to summarize her personal opinion on CO_2-based economies: (1) no single CO_2 reduction method will prevail as the only valid one, (2) each of the chemical and biochemical CO_2 reduction processes mentioned is energy intensive and complex, (3) the use of CO_2 as a future carbon source is unquestion.

FUNDING

LEAD project TU Graz "DigiBioTech Digitalization of Biotechnology", 2025 to 2027. H2020-MSCA-ITN-2020 "ConCO$_2$rde Training network on the conversion of CO_2 by smart autotrophic biorefineries", 2021 to 2024. Lighthouse project "Synthetic biology for efficient gas feedstock conversion to new protein sources", within the FFG Comet K2 ACIB, 2020 to 2023.

Figure 2. The team from the Institutes of Biotechnology and Biochemical Engineering and Thermal Engineering. From left to right Vera Lambauer (Biote), Markus Müller (IWT), Regina Kratzer (Biote) and Markus Raiber (IWT), in front of the newly designed bioreactor for use in oxyhydrogen fermentations. The bioreactor with medium and cell culture is shown on the right.

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