Recycling Carbon: A Leap towards Greener Chemicals

By YAN Fusheng

Imagine a world where carbon dioxide (CO_2) emissions that contribute to global warming are not only captured but transformed into something valuable. Scientists have now engineered a new method that could make this vision a reality, offering a new twist on carbon fixation.

Turning pollutants into products: a new technique uses electricity and hydrogen to make useful chemicals from CO_2. (Image created using DALL-E by YAN Fusheng)

In a recent *Nature* study on January 31, a joint team of researchers developed a proton-exchange membrane (PEM) system that can efficiently and durably convert carbon dioxide (CO_2) into formic acid (HCOOH), a valuable chemical used in various industries. This innovative technology could potentially contribute to a more sustainable and carbon-neutral future by recycling CO_2 emissions and harnessing renewable energy sources.

The team, led by Dr. YAO Tao from the University of Science and Technology of China (USTC) and his collaborators from the Huazhong University of Science and Technology and the University of Auckland, has overcome a long-standing challenge in CO_2 electrolysis – the formation of carbonate precipitates. These precipitates typically limit carbon utilization and system stability, hindering the widespread adoption of CO_2 conversion technologies.

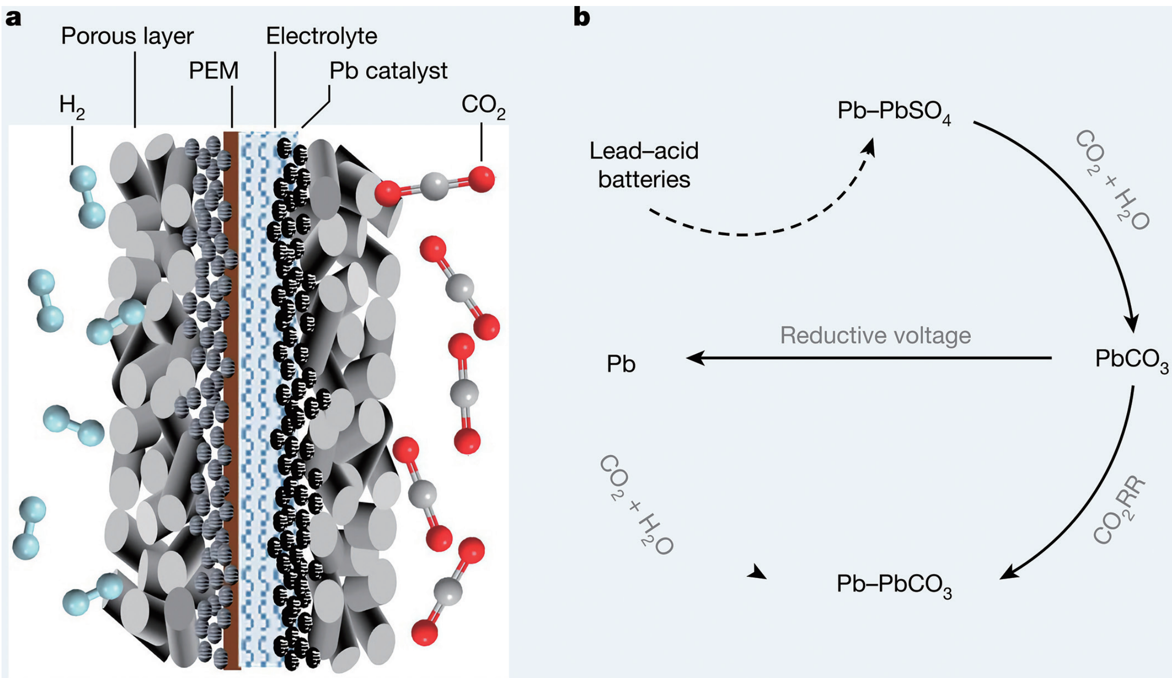
Previous attempts to address this issue, such as physical washing, pulsed operation, and the use of specialized membranes, have only provided partial solutions. Breaking through the bottleneck, the researchers have elegantly solved the problem by developing a PEM system that operates in an acidic environment, where carbonate precipitation does not occur.

At the heart of this breakthrough lies a robust and efficient catalyst derived from waste lead-acid batteries. This recycled lead (r-Pb) catalyst, when coupled with a stable three-phase interface and a durable membrane, enables the direct conversion of CO_2 to formic acid with an exceptional Faradaic efficiency of over 93%.

Remarkably, the PEM system achieved a high single-pass conversion efficiency of around 91% for CO_2 at a current density of 600 milliamperes per square centimeter (mA/cm^2) and a cell voltage of 2.2 volts. Moreover, it demonstrated unparalleled stability, operating continuously for more than 5,200 hours, a significant improvement over current CO_2 reduction systems that typically last around 100 hours.

One of the key innovations lies in the coupling of CO_2 reduction at the cathode with hydrogen oxidation at the anode. This approach not only decreases overall energy consumption but also prevents the formation of harmful hydrogen peroxide, which could degrade or destroy the PEM.

The researchers' comprehensive characterizations and theoretical analyses have identified the formation of



Schematic illustration of the concept proton-exchange membrane (PEM) electrolyzer (a) and the catalyst phase transition (b) for efficiently reducing carbon dioxide (CO^2) to valuable chemicals. (Image by FANG *et al.*)

interfaces between lead and lead carbonate as crucial for efficient CO_2 activation. They propose a lattice carbon activation mechanism, where the catalyst's carbonate site is reduced, forming a vacancy (an empty space in the lead carbonate lattice structure). This mechanism accounts for the high efficiency of CO_2 reduction observed in the acidic environment.

"Although CO_2 electrolysis towards formic acid in an acidic environment has been demonstrated before, stability has remained a key unsolved challenge. The crucial advance made in this work is the substantial improvement of acidic-environment stability, while maintaining a high level of performance and improving the economics by using a hydrogen oxidation reaction on the anode," commented Dr. Feng Jiao, a professor at Washington University who is not involved in this work.

While the study focuses on formic acid production, the researchers plan to explore other carbon products through catalyst design and computational techniques like density functional theory and machine learning. This approach could remarkably advance the field of CO_2 reduction technology.

The potential implications of this breakthrough are far-reaching. By enabling efficient and durable CO_2 conversion using renewable energy sources, it could contribute to a more sustainable and carbon-neutral future, reducing the reliance on fossil fuels and mitigating the impact of greenhouse gas emissions on the environment.

However, the researchers admit that the widespread adoption of this technology will depend on the availability of truly renewable and affordable electricity, CO_2, and hydrogen sources.

Despite the challenges, this study represents a significant step forward in the quest for sustainable solutions to the climate crisis, demonstrating the power of scientific innovation and collaboration.

Reference

Fang, W., Guo, W., Lu, R., Yan, Y., Liu, X., Wu, D., . . . Xia, B. Y. (2024). Durable CO_2 conversion in the proton-exchange membrane system. *Nature, 626*(7997), 86-91. doi:10.1038/s41586-023-06917-5