New sugar-based catalyst could offer a potential solution for using captured carbon

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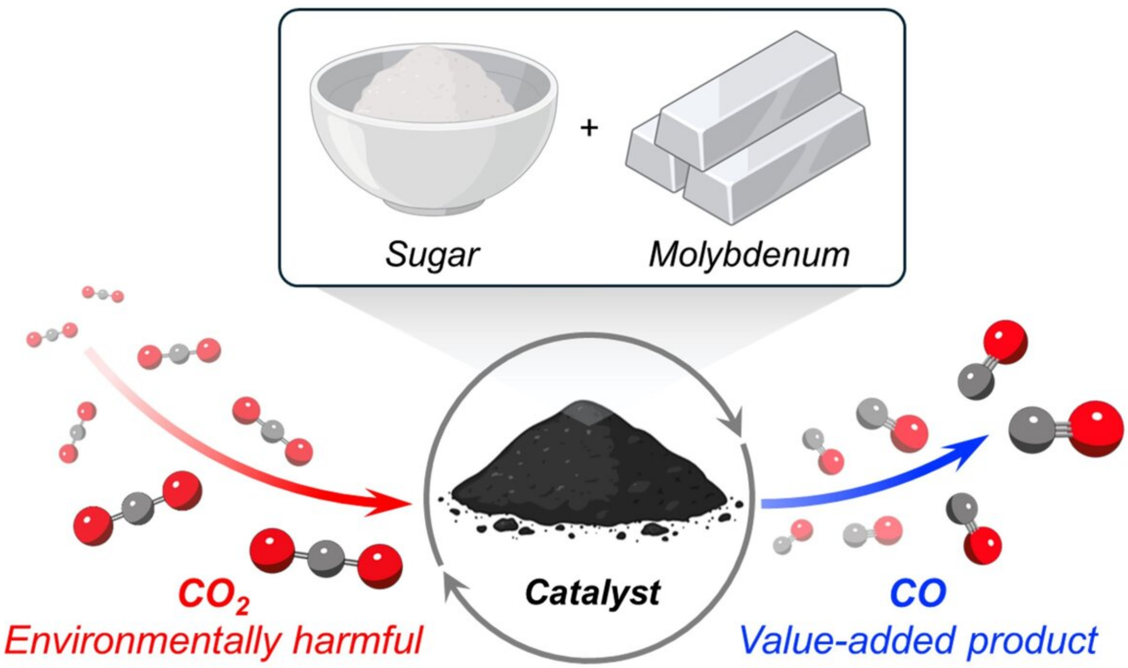

This schematic shows the full process of creating the catalyst and using it to convert carbon dioxide. Credit: Milad Khoshooei

A new catalyst made from an inexpensive, abundant metal and common table sugar has the power to destroy carbon dioxide (CO_2) gas.

In a new Northwestern University study, the catalyst successfully converted CO_2 into carbon monoxide (CO), an important building block to produce a variety of useful chemicals. When the reaction occurs in the presence of hydrogen, for example, CO_2 and hydrogen transform into synthesis gas (or syngas), a highly valuable precursor to producing fuels that can potentially replace gasoline.

With recent advances in carbon capture technologies, post-combustion carbon capture is becoming a plausible option to help tackle the global climate change crisis. But how to handle the captured carbon remains an open-ended question. The new catalyst potentially could provide one solution for disposing of the potent greenhouse gas by converting it into a more valuable product.

The study, titled "An active, stable cubic molybdenum carbide catalyst for the high-temperature reverse water-gas shift reaction," is published in the journal *Science*.

"Even if we stopped emitting CO_2 now, our atmosphere would still have a surplus of CO_2 as a result of industrial activities from the past centuries," said Northwestern's Milad Khoshooei, who co-led the study.

"There is no single solution to this problem. We need to reduce CO_2 emissions and find new ways to decrease the CO_2 concentration that is already in the atmosphere. We should take advantage of all possible solutions."

"We're not the first research group to convert CO_2 into another product," said Northwestern's Omar K. Farha, the study's senior author. "However, for the process to be truly practical, it necessitates a catalyst that fulfills several crucial criteria: affordability, stability, ease of production and scalability. Balancing these four elements is key. Fortunately, our material excels in meeting these requirements."

An expert in carbon capture technologies, Farha is the Charles E. and

Emma H. Morrison Professor of Chemistry at Northwestern's Weinberg College of Arts and Sciences. After starting this work as a Ph.D. candidate at the University of Calgary in Canada, Khoshooei now is a postdoctoral fellow in Farha's laboratory.

Solutions from the pantry

The secret behind the new catalyst is molybdenum carbide, an extremely hard ceramic material. Unlike many other catalysts that require expensive metals, such as platinum or palladium, molybdenum is an inexpensive, non-precious, Earth-abundant metal.

To transform molybdenum into molybdenum carbide, the scientists needed a source of carbon. They discovered a cheap option in an unexpected place: the pantry. Surprisingly, sugar—the white, granulated kind found in nearly every household—served as an inexpensive, convenient source of carbon atoms.

"Every day that I tried to synthesize these materials, I would bring sugar to the lab from my home," Khoshooei said. "When compared to other classes of materials commonly used for catalysts, ours is incredibly inexpensive."

Successfully selective and stable

When testing the catalyst, Farha, Khoshooei and their collaborators were impressed by its success. Operating at ambient pressures and high temperatures (300–600 degrees Celsius), the catalyst converted CO_2 into CO with 100% selectivity.

High selectivity means that the catalyst acted only on the CO_2 without disrupting surrounding materials. In other words, industry could apply the catalyst to large volumes of captured gases and selectively target only the CO_2. The catalyst also remained stable over time, meaning that it stayed active and did not degrade.

"In chemistry, it's not uncommon for a catalyst to lose its selectivity after a few hours," Farha said. "But, after 500 hours in harsh conditions, its selectivity did not change."

This is particularly remarkable because CO_2 is a stable—and stubborn—molecule.

"Converting CO_2 is not easy," Khoshooei said. "CO_2 is a chemically stable molecule, and we had to overcome that stability, which takes a lot of energy."

Tandem approach to carbon clean-up

Developing materials for carbon capture is a major focus of Farha's laboratory. His group develops metal-organic frameworks (MOFs), a class of highly porous, nano-sized materials that Farha likens to "sophisticated and programmable bath sponges." Farha explores MOFs for diverse applications, including pulling CO_2directly from the air.

Now, Farha says MOFs and the new catalyst could work together to play a role in carbon capture and sequestration.

"At some point, we could employ a MOF to capture CO_2, followed by a catalyst converting it into something more beneficial," Farha suggested. "A tandem system utilizing two distinct materials for two sequential steps could be the way forward."

"This could help us answer the question: 'What do we do with captured CO_2?'" Khoshooei added.

"Right now, the plan is to sequester it underground. But underground reservoirs must meet many requirements in order to safely and permanently store CO_2. We wanted to design a more universal solution that can be used anywhere while adding economic value."

More information: Milad Ahmadi Khoshooei et al, An active, stable cubic molybdenum carbide catalyst for the high-temperature reverse water-gas shift reaction, *Science* (2024). DOI: 10.1126/science.adl1260. www.science.org/doi/10.1126/science.adl1260

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