Vanadium research makes key advance for capturing carbon from the air

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Vanadium, one of the CO_2 capture materials, displaying a brilliant deep purple color. Credit: May Nyman, chemistry professor, OSU College of Science

A chemical element so visually striking it was named for a goddess shows a "Goldilocks" level of reactivity—neither too much nor too little—that makes it a strong candidate as a carbon scrubbing tool.

The element is vanadium, and research by Oregon State University scientists, published in *Chemical Science*, has demonstrated the ability of vanadium peroxide molecules to react with and bind carbon dioxide—an important step toward improved technologies for removing carbon dioxide from the atmosphere.

The study is part of a $24 million federal effort to develop new methods for direct air capture, or DAC, of carbon dioxide, a greenhouse gas that's produced by the burning of fossil fuels and is associated with climate change.

Facilities that filter carbon from the air have begun to spring up around the globe but they're still in their infancy. Technologies for mitigating carbon dioxide at the point of entry into the atmosphere, such as at power plants, are more well developed. Both types of carbon capture will likely be needed if the Earth is to avoid the worst outcomes of climate change, scientists say.

In 2021 Oregon State's May Nyman, the Terence Bradshaw Chemistry Professor in the College of Science, was chosen as the leader of one of nine direct air capture projects funded by the Department of Energy. Her team is exploring how some transition metal complexes can react with air to remove carbon dioxide and convert it to a metal carbonate, similar to what is found in many naturally occurring minerals.

Transition metals are located near the center of the periodic table and their name arises from the transition of electrons from low energy to high energy states and back again, giving rise to distinctive colors. For this study, the scientists landed on vanadium, named for Vanadis, the old Norse name for the Scandinavian goddess of love said to be so beautiful her tears turned to gold.

Nyman explains that carbon dioxide exists in the atmosphere at a density of 400 parts per million. That means for every 1 million air molecules, 400 of them are carbon dioxide, or 0.04%.

"A challenge with direct air capture is finding molecules or materials that are selective enough, or other reactions with more abundant air molecules, such as reactions with water, will outcompete the reaction with CO_2," Nyman said. "Our team synthesized a series of molecules that contain three parts that are important in removing carbon dioxide from the atmosphere, and they work together."

One part was vanadium, so named because of the range of beautiful colors it can exhibit, and another part was peroxide, which bonded to the vanadium. Because a vanadium peroxide molecule is negatively charged, it needed alkali cations for charge balance, Nyman said, and the researchers used potassium, rubidium and cesium alkali cations for this study.

She added that the collaborators also tried substituting other metals from the same neighborhood on the periodic table for vanadium.

"Tungsten, niobium and tantalum were not as effective in this chemical form," Nyman said. "On the other hand, molybdenum was so reactive it exploded sometimes."

In addition, the scientists substituted ammonium and tetramethyl ammonium, the former of which is mildly acidic, for the alkalis. Those compounds didn't react at all, a puzzler the researchers are still trying to understand.

"And when we removed the peroxide, again, not so much reactivity," Nyman said. "In this sense, vanadium peroxide is a beautiful, purple Goldilocks that becomes golden when exposed to air and binds a carbon dioxide molecule."

She notes that another valuable characteristic of vanadium is that it allows for the comparatively low release temperature of about 200°C for the captured carbon dioxide.

"That's compared to almost 700°C when it is bonded to potassium, lithium or sodium, other metals used for carbon capture," she said. "Being able to rerelease the captured CO_2 enables reuse of the carbon capture materials, and the lower the temperature required for doing that, the less energy that's needed and the smaller the cost. There are some very clever ideas about reuse of captured carbon already being implemented—for example, piping the captured CO_2 into a greenhouse to grow plants."

Other Oregon State authors on the paper included Tim Zuehlsdorff, assistant professor of theoretical/physical chemistry, and postdoctoral researcher Eduard Garrido.

"I'm also really proud of the hard work of the graduate students in my lab, Zhiwei Mao and Karlie Bach, and undergraduate Taylor Linsday," Nyman said. "This is a brand new area for my lab, as well as for Tim Zuehlsdorff, who supervised Ph.D. student Jacob Hirschi on the computational studies to explain the reaction mechanisms. Starting a new area of study involves many unknowns."

More information: Eduard Garrido Ribó et al, Implementing vanadium peroxides as direct air carbon capture materials, *Chemical Science* (2023). DOI: 10.1039/D3SC05381D

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