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Alf

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ALF

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As the demand for energy grows around the world, and solutions are sought for mitigating the consequences of burning fossil fuels, high performing and scalable adsorbent materials are vitally important. Adsorbent materials are unique, as their atomic crystal structures are often porous, and this porosity can enable capture and storage of certain gasses at useful temperatures and pressures. Given many issues in the world today center around storing/capturing gas molecules, such as capturing CO_2 to prevent its escape into the atmosphere or storing H_2 for use as a long-term energy source, new and high performing adsorbent materials are crucial for the future energy economy. Like all materials though, how an adsorbent performs depends intimately on its chemical composition and atomic structure. Often, given the nature of chemistry of each specific adsorbent, an adsorbent will be best paired with just one (or few) specific gas storage/separation process. This is because the types of separations/storage of gasses can vary considerably in their temperature/pressure conditions.

In the case of capturing CO_2 from a fuel plant, temperatures of exhaust streams can be upwards of 50 to 70 degrees Celsius, as well as very humid and caustic. In the case of storing hydrogen gas, conditions for useful application require temperatures to be as close to room temperature as possible (to reduce energy cost), but this is incredibly difficult to achieve. This is because H_2 gas is the lightest of all gas molecules and lacks chemical "hooks" for adsorbents to easily grab onto (no dipole or quadripolar moment, no reactive functional group). However, one such material that has been studied by scientists at the NCNR and their collaborators around the

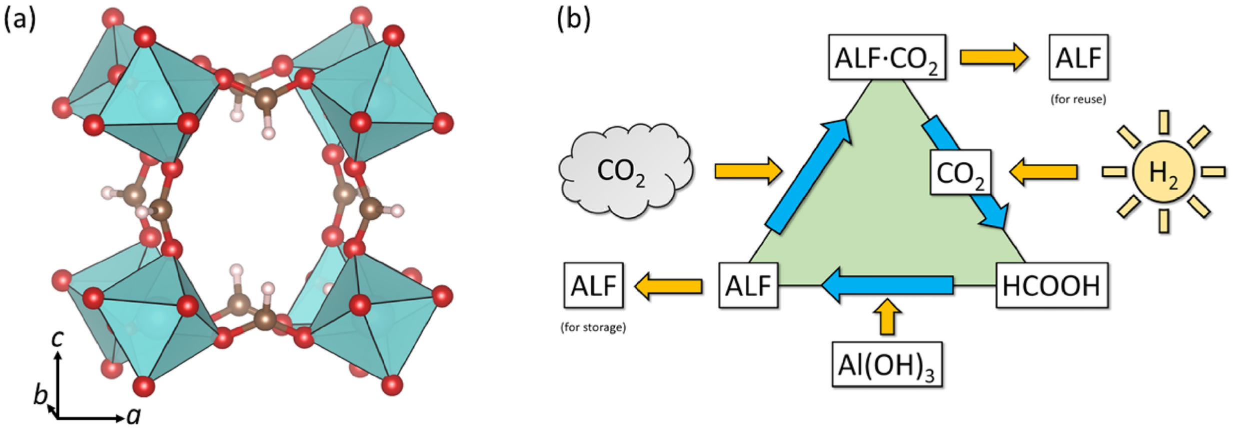

Figure 1. (a) Cage structure of ALF when empty (data acquired at BT-1, NCNR). (b) ALFs promise as a future material in the CO_2 capture cycle, when coupled with solar power generated H_2 gas and reduction of captured CO_2.

world, is thought to be a viable solution to point source CO_2 capture and grid scale H_2 storage, as well as other major industrial interests. The material studied is aluminum formate, or as it is now commonly referred to in the scientific literature, ALF (Figure 1a). ALF distinguishes itself from many other adsorbents not only with its excellent performance in a diversity of gas separations and storages, but also in its simple preparation from commodity chemicals ($Al(OH)_3$ and formic acid) and promise of scalability.

What has been shown by the scientists at the NCNR and their collaborators is that ALF's simple cage like crystal structure makes it useful for adsorbing certain gasses, and not others. Neutrons, and the *in-situ* capabilities developed at the NCNR, proved important to understanding how the adsorbed gasses interacts with ALFs cage structure.

In the case of using ALF for CO_2 capture, ALF adsorbs CO_2 at elevated temperatures in high amounts (and can be easily regenerated), but also does so without adsorbing N_2. Given that exhaust gas from fuel plants is predominantly CO_2 (15 percent) and N_2 (85 percent), this selectivity performance is an elusive prerequisite for any possible CO_2 capture material.

However, ALF's downside is that though it is air stable, it cannot survive the oppressive humidities seen in pure combustion exhaust streams. For many other materials, this instability prevents use, given that many adsorbents with comparable performance to ALF are also expensive to make, ≈20 to 100 dollars per kilogram (or above). Appreciating that a single coal plant produces ≈10,000 tons of CO_2 per day, and there are ≈300 coal plants operating in the USA, large amounts of adsorbent are likely needed to be effective. Yet, ALF's low cost (approximately 1 to 2 dollars per kg), likely enables pairing with humidity lowering steps, whilst still being cheaper than using other adsorbents. Lastly, given that ALF is made from formic acid, and $Al(OH)_3$ (a waste product of aluminum metal processing) ALF also represents a likely keystone material for a future CO_2 capture economy (Figure 1b) when paired with future solar energy generated H_2 gas. This opens the question of what to do with potentially massive quantities of ALF.

In addition to ALF's ability to separate O_2 from N_2, or CO_2 from any hydrocarbon (including acetylene), NCNR researchers revealed that ALF can store appreciable amounts of H_2 gas at moderate temperatures (120 K to 200 K) and moderate pressures (1 to 20 bar). At first glance, ALFs dense crystal structure prevents it from storing a lot of H_2 per gram of material, a usually important metric. However, given ALFs low cost and H_2 adsorption performance at convenient conditions, technoeconomic analysis indicates that ALF stores H_2 per dollar at comparable amounts seen with simply compressing H_2, but with a fraction of the pressure (15 bar vs. 350 bar). This means that ALF offers a path to large scale grid scale storage of H_2, a necessity for any future H_2 based economy.

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