Stimulating New Carbon Capture Technologies through Basic Research

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Chairman Johnson, Ranking Member Lucas, and distinguished Members of the Committee. Thank you for inviting me to testify today and for your interest in carbon capture science and technology development. My name is Jeffrey Long and I am a Faculty Senior Scientist at the Lawrence Berkeley National Laboratory and a Professor at the University of California, Berkeley. My testimony is my own and does not necessarily reflect the views of the U.S. Department of Energy, Berkeley Lab, or the University of California.

Fossil fuels are projected to continue to supply the majority of global energy for at least the next several decades, and thus, in addition to the fervent pursuit of renewable energy technologies, it is critical to invest in carbon capture technologies that will stem the buildup of greenhouse gases in our atmosphere. Support for basic scientific research plays a vital role in the quest for efficient, economical carbon capture technologies needed for the well-being of life on our planet. Here, I present a case study that underscores this point.

I serve as Director of a Department of Energy-funded Energy Frontier Research Center (EFRC), the Center for Gas Separations (www.cchem.berkeley.edu/co2efrc), which is based in Berkeley. The goal of our center is to create new materials that enable the energy-efficient separation of gas mixtures, as required for the cleaner use of fossil fuels and for reducing industrial emissions. Particular emphasis is placed on separations that can reduce carbon dioxide (CO_2) emissions from power plants and lower the cost of large-scale gas separations performed in industry and agriculture. Toward this end, we create new porous solid materials known as metal–organic frameworks (MOFs). These materials behave as finely-tuned sponges, capable of soaking up vast quantities of a specific gas molecule, such as CO_2. MOFs are particularly powerful for such applications, owing to their chemically controllable structure and their extremely high internal surface areas. Indeed, just one gram of a MOF, an amount similar to a cube of sugar, can have a surface area greater than that of a football field. Consequently, if designed properly, a small amount of MOF can serve to remove an enormous amount of CO_2 from a gas mixture, such as the exhaust gas produced upon combusting fossil fuels.

Working with a team of scientists in the Center for Gas Separations, we serendipitously discovered that certain MOFs can capture carbon dioxide in a cooperative fashion, similar to how hemoglobin is known to bind and release oxygen in the body. In these unprecedented materials, an initial reaction with CO_2 sets off a chain reaction that causes the uptake of more and more CO_2 molecules, rapidly filling the pores of the solid. Importantly, the MOFs exhibit a specific affinity for binding CO_2 over other gas molecules, such as nitrogen (N_2) and oxygen (O_2), which are the other main components of a flue gas created upon burning fossil fuels. What is particularly exceptional about these materials is that the uptake of CO_2 depends critically upon temperature and pressure, such that, with judicious separation process design, one can envision using them in a system where CO_2 can be captured and then released in pure form for utilization or sequestration with minimal energy input. It is important to emphasize that intensive collaboration among a team of talented scientists with diverse backgrounds, the cornerstone of the EFRC program, was essential to gaining an understanding of why these materials behave in this unexpected manner. Beyond the instrumental role of the EFRC program, our research was aided substantially by access to national laboratory resources, such as at the Advanced Light Source and The Molecular Foundry at Lawrence Berkeley National Laboratory (LBNL).

Our discovery subsequently led to a Department of Energy ARPA-e project focused on learning how to adjust the CO_2 adsorption properties of the new materials, enabling us to customize them for efficient removal of CO_2 from a power plant flue gas. In the course of these efforts, we also generated a number of variants of the materials that are highly efficient for the removal of CO_2 from other gas mixtures, including biogas, natural gas, and even directly from air. The resulting solids all exhibit high capacities for CO_2—even in the presence of water vapor—and a single sample of material can be reused hundreds of times for the removal of carbon dioxide from large volumes of gas. Importantly, this recycling requires only small changes in temperature and gas pressure, and the materials can capture more than five times the amount of CO_2 trapped by state-of-the-art aqueous amine solutions currently used in industry. Ultimately, these MOFs have the potential to separate CO_2 from mixtures with minimal energy input, and for example could achieve carbon capture from a flue gas using only low-value heat in a power plant. This strategy would eliminate the need to divert high-temperature steam away from power production to carbon capture, avoiding a large increase in the cost of electricity, which is a common critique of other carbon capture technology designs.

The potential applications of these MOFs led to the formation of a start-up company, Mosaic Materials, Inc. (mosaicmaterials.com), in 2014. Significantly, in its initial stages, the company was the first project accepted into the Cyclotron Road incubator program (www.cyclotronroad.org) at LBNL, which enabled a demonstration of how the new carbon capture technology might be deployed at scale. This led to success in raising venture capital, and Mosaic Materials is now actively pursuing the development, optimization, and large-scale commercial production of these materials for integration within numerous carbon dioxide separation processes, including its efficient, low-cost removal of CO_2 from air, biogas, natural gas, and flue gases. The company has already developed straightforward, inexpensive, and scalable methods for the production of key MOFs in a variety of forms and in particular has demonstrated the capacity and potential of the materials for performing carbon dioxide separations. More than $7M in government support has been raised to facilitate these efforts, including from the Department of Energy for carbon capture from coal-fired power plants, the Navy for efficiently scrubbing CO_2 from submarine atmospheres, and NASA for CO_2 capture in life support applications associated with space travel. The company has further succeeded in forming a number of strategic partnerships with other companies with an interest in carbon capture, including ExxonMobil.

LBNL is now leading a project in which Mosaic Materials is working with Svante, Inc. (svanteinc.com) to carry out a pilot demonstration at a coal-fired power plant (the National Carbon Capture Center in Wilsonville, Alabama) that incorporates the MOF technology within a unique rotating bed system to achieve large capture rates with quick process cycle times and reduced energy consumption—equating to high performance with reduced cost. Additionally, we are working with the National Energy Technology Laboratory on the multi-institutional Carbon Capture Simulation for Industry Impact ($CCSI^2$, www.netl.doe.gov/coal/carbon-capture/ccsi2) program to compare implementation of this MOF technology with existing carbon capture technologies. This program is also investigating other processes where these unique MOF materials might be employed to achieve key separations, with the ultimate goal of identifying the most efficient and economical means of deploying the materials in a capture process. It is expected that there will be wide-spread commercialization of these exceptional materials in industry and power generation sectors, resulting in a dramatic reduction in the cost and energy associated with carbon capture as it necessarily becomes implemented across the globe.

Ultimately, the discovery of these unprecedented new carbon capture materials would not have been possible without basic research support at numerous stages—through larger programs such as the EFRCs and smaller programs, such as those spearheaded by national laboratories. If we are to halt global warming, it is essential that we continue to champion and even increase such support for basic science. Moreover, we need to invest intensively in accelerating the most promising new discoveries toward technology realization. This is a difficult, slow, and expensive process, but one that is of vital importance to our future.

Again, thank you for inviting me to testify at this important hearing. I look forward to answering any questions that you may have.

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