MIT Technology Review

Can Sucking CO_2 Out of the Atmosphere Really Work?

A Columbia scientist and his startup think they have a plan to save the world. Now they have to convince the rest of us.

By Eli Kintisch on October 7, 2014
14 comments

Physicist Peter Eisenberger had expected colleagues to react to his idea with skepticism. He was claiming, after all, to have invented a machine that could clean the atmosphere of its excess carbon dioxide, making the gas into fuel or storing it underground. And the Columbia University scientist was aware that naming his two-year-old startup Global Thermostat hadn't exactly been an exercise in humility.

But the reception in the spring of 2009 had been even more dismissive than he had expected. First, he spoke to a special committee convened by the American Physical Society to review possible ways of reducing carbon dioxide in the atmosphere through so-called air capture, which means, essentially, scrubbing it from the sky. They listened politely to his presentation but barely asked any questions. A few weeks later he spoke at the U.S. Department of Energy's National Energy Technology Laboratory in West Virginia to a similarly skeptical audience. Eisenberger explained that his lab's research involves chemicals called amines that are already used to capture concentrated carbon dioxide emitted from fossil-fuel power plants. This same amine-based technology, he said, also showed potential for the far more difficult and ambitious task of capturing the gas from the open air, where carbon dioxide is found at concentrations of 400 parts per million. That's up to 300 times more diffuse than in power plant smokestacks. But Eisenberger argued that he had a simple design for achieving the feat in a cost-effective way, in part because of the way he would recycle the amines. "That didn't even register," he recalls. "I felt a lot of people were pissing on me."

The next day, however, a manager from the lab called him excitedly. The DOE scientists had realized that amine samples sitting around the lab had been bonding with carbon dioxide at room temperature—a fact they hadn't much appreciated until then. It meant that Eisenberger's approach to air capture was at least "feasible," says one of the DOE lab's chemists, Mac Gray.

Five years later, Eisenberger's company has raised $24 million in investments, built a working demonstration plant, and struck deals to supply at least one customer with carbon dioxide harvested from the sky. But the next challenge is proving that the technology could have a transformative impact on the world, befitting his company's name.

The need for a carbon-sucking machine is easy to see. Most technologies for mitigating carbon dioxide work only where the gas is emitted in large concentrations, as in power plants. But air-capture machines, installed anywhere on earth, could deal with the 52 percent of carbon-dioxide emissions that are caused by distributed, smaller sources like cars, farms, and homes. Secondly, air capture, if it ever becomes practical, could gradually reduce the concentration of carbon dioxide in the atmosphere. As emissions have accelerated—they're now rising at 2 percent per year, twice as rapidly as they did in the last three decades of the 20th century—scientists have begun to recognize the urgency of achieving so-called "negative emissions."

The obvious need for the technology has enticed several other efforts to come up with various approaches that might be practical. For example, Climate Engineering, based in Calgary, captures carbon using a liquid solution of sodium hydroxide, a well-established industrial technique. A firm cofounded by an early pioneer of the idea, Eisenberg's Columbia colleague Klaus Lackner, worked on the problem for several years before giving up in 2012.

"Negative emissions are definitely needed to restore the atmosphere given that we're going to far exceed any safe limit for CO_2, if there is one. The question in my mind is, can it be done in an economical way?"

A report released in April by the Intergovernmental Panel on Climate Change says that avoiding the internationally agreed upon goal of 2 °C of global warming will likely require the global deployment of "carbon dioxide removal" strategies like air capture. (See "The Cost of Limiting Climate Change Could Double without Carbon Capture Technology.") "Negative emissions are definitely needed to restore the atmosphere given that we're going to far exceed any safe limit for CO_2, if there is one," says Daniel Schrag, director of the Harvard University Center for the Environment. "The question in my mind is, can it be done in an economical way?"

Most experts are skeptical. (See "What Carbon Capture Can't Do.") A 2011 report by the American Physical Society identified key physical and economic challenges. The fact that carbon dioxide will bind with amines, forming a molecule called a carbamate, is well known chemistry. But carbon dioxide still represents only one in 2,500 molecules in the air. That means an effective air-capture machine would need to push vast amounts of air past amines to get enough carbon dioxide to stick to them and then regenerate the amines to capture more. That would require a lot of energy and thus be very expensive, the 2011 report said. That's why it concluded that air capture "is not currently an economically viable approach to mitigating climate change."

The people at Global Thermostat understand these daunting economics but remain defiantly optimistic. The way to make air capture profitable, says Global Thermostat cofounder Graciela Chichilnisky, a Columbia University economist and mathematician, is to take advantage of the demand for the gas by various industries. There already exists a well-established, billion-dollar market for carbon dioxide, which is used to rejuvenate oil wells, make carbonated beverages, and stimulate plant growth in commercial greenhouses. Historically, the gas sells for around $100 per ton. But Eisenberger says his company's prototype machine could extract a concentrated ton of the gas for far less than that. The idea is to first sell carbon dioxide to niche markets, such as oil-well recovery, to eventually create bigger ones, like using catalysts to make fuels in processes that are driven by solar energy. "Once capturing carbon from the air is profitable, people acting in their own self-interest will make it happen," says Chichilnisky.

Warming up

Eisenberger and Chichilnisky were colleagues at Columbia in 2008 when they realized that they had complementary interests: his in energy, and hers in environmental economics, including work to help shape the 1991 Kyoto Protocol, the first global treaty on cutting emissions. Nations had pledged big cuts, says Chichilnisky, but economic and political realities had provided "no way to implement it." The pair decided to create a business to tackle the carbon challenge.

They focused on air capture, which was first developed by Nazi scientists who used liquid sorbents to remove accumulations of CO_2 in submarines. In the winter of 2008 Eisenberger sequestered himself in a quiet house with big glass windows overlooking the ocean in Mendocino County, California. There he studied existing literature on capturing carbon and made a key decision. Scientists developing techniques to capture CO_2 have thus far sought to work at high concentrations of the gas. But Eisenberger and Chichilnisky focused on another term in those equations: temperature.

Engineers have previously deployed amines to scrub CO_2 from flue gases, whose temperatures are around 70 °C when they exit power plants. Subsequently removing the CO_2 from the amines—"regenerating" the amines—generally requires reactions at 120 °C. By contrast, Eisenberger calculated that his system would operate at roughly 85 °C, requiring less total energy. It would use relatively cheap steam for two purposes. The steam would heat the surface, driving the CO_2 off the amines to be collected, while also blowing CO_2 away from the surface.

Even if air capture were to someday prove profitable, whether it should be scaled up is another question.

The upshot? With less heat-management infrastructure than what is required with amines in the smokestacks of power plants, the design of a scrubber could be simpler and therefore cheaper. Using data from their prototype, Eisenberger's team figures the approach could cost between $15 and $50 per ton of carbon dioxide captured from air, depending on how long the amine surfaces last.

If Global Thermostat can achieve anywhere near the prices it's touting, a number of niche markets beckon. The startup has partnered with a Carson City, Nevada-based company called Algae Systems to make biofuels using carbon dioxide and algae. Meanwhile the demand is rising for carbon dioxide to inject into depleted oil wells, a technique known as enhanced oil recovery. One study estimates that the application could require as much as 3 billion tons of carbon dioxide annually by 2021, a nearly tenfold increase over the 2011 market.

That still represents a drop in the bucket in terms of the amounts needed to reduce or even stabilize the concentration of CO_2 in the atmosphere. But Eisenberger says there are really no alternatives to air capture. Simply capturing carbon emissions from coal-fired power plants, he says, only extends society's dependence on carbon-intensive coal.

Suck it up

It's a warm December afternoon in Silicon Valley as Eisenberger and I make our way across SRI International's concrete research center. It's in these low-slung buildings where engineers first developed ARPAnet, Apple's Siri software, and countless other technological advances. About a quarter mile from the entrance, a 40-foot-high tower of fans, steel, and silver tubes comes into view. This is the Global Thermostat demonstration plant. It's imposing and clean. Eisenberger gazes at the quiet scene around the tower, which includes a tall tree. "It's doing exactly what the tree is doing," says Eisenberger. But then he corrects himself. "Well, actually, it's doing it a lot better."

After Eisenberger earned a PhD physics in 1967 at Harvard, stints at Bell Labs, Princeton, and Stanford followed. At Exxon in the 1980s he led work on solar energy, then served as director of Lamont-Doherty, the geosciences lab at Columbia. There he has taught a long-standing seminar called "The Earth/Human system." It was in that seminar, in 2007, with Lackner as a guest lecturer, that Eisenberger first heard about air capture. After a year or so of preparation, he and Chichilnisky reached out to billionaire Edgar Bronfman Jr. "Sometimes when you hear something that must be too good to be true, it's because it is," was Bronfman's reaction, according to his son, who was present at the meeting. But the scion implored his father: "If they're right, this is one of the biggest opportunities out there." The family invested $18 million.

That largesse has allowed the company to build its demonstration despite basically no federal support for air capture research. (Global Thermostat chose SRI as its site due to the facility's prior experience with carbon-capture technology.) The rectangular tower uses fans to draw air in over alternating 10-foot-wide surfaces known as contactors. Each is comprised of 640 ceramic cubes embedded with the amine sorbent. The tower raises one contactor as another is lowered. That allows the cubes of one to collect CO_2 from ambient air while the other is stripped of the gas by the application of the steam, at 85 °C. For now that gas is simply vented, but depending on the customer it could be injected into the ground, shipped by pipe, or transferred to a chemical plant for industrial use.

A key challenge facing the company is the ruggedness of the amine sorbent surfaces. They tend to decay rapidly when oxidized, and frequently replacing the sorbents could make the process much less cost-effective than Eisenberger projects.

False hope

None of the world's thousands of coal plants have been outfitted for full-scale capture of their carbon pollution. And if it isn't economical for use in power plants, with their concentrated source of carbon dioxide, the prospects of capturing it out of the air seem dim to many experts. "There's really little chance that you could capture CO_2 from ambient air more cheaply than from a coal plant, where the flue gas is 300 times more concentrated," says Robert Socolow, director of the Princeton Environment Institute and co-director of the university's carbon mitigation initiative.

Adding to the skepticism over the feasibility of air capture is that there are other, cheaper ways to create the so-called negative emissions. A more practical way to do it, Schrag says, would involve deriving fuels from biomass—which removes CO_2 from the atmosphere as it grows. As that feedstock is fermented in a reactor to create ethanol, it produces a stream of pure carbon dioxide that can be captured and stored underground. It's a proven technique and has been tested at a handful of sites worldwide.

Even if air capture were to someday prove profitable, whether it *should* be scaled up is another question. Say a solar power plant is built outside an existing coal plant. Should the energy the new solar plant produces be used to suck carbon out of the atmosphere, or to allow the coal plant to be shut down by replacing its energy output? The latter makes much more sense, says Socolow. He and others have another concern about air capture: that claims about its feasibility could breed complacency. "I don't want us to give people the false hope that air capture can solve the carbon emissions problem without a strong focus on [reducing the use of] fossil fuels," he says.

Eisenberger and Chichilnisky are adamant about the importance of sucking CO_2out of the atmosphere rather than focusing entirely on capturing it from coal plants. In 2010, the pair developed a version of their technology that mixes air with flue gas from a coal or gas-fired power plant. That approach provides a source of steam while capturing both atmospheric carbon and new emissions. It also could lower costs by providing a higher concentration of CO_2 for the machine to capture. "It's a very impressive system, a triumph," says Socolow, who thinks scientific advances made in air capture will eventually be used primarily on coal and gas power plants.

Such an application could play a critical role in cleaning up greenhouse gas emissions. But Eisenberger has revealed even loftier goals. A patent granted to him and Chichilnisky in 2008 described air capture technology as, among other things, "a global thermostat for controlling average temperature of a planet's atmosphere."

Eli Kintisch is a correspondent for Science *magazine.*