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The business of cooling the planet

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Climate scientists and their billionaire backers, like Bill Gates, are trying to turn down the global thermostat - and make money doing it.

*By **Marc Gunther**, contributor*


ILLUSTRATION: APIRAT INPAHSAENG

FORTUNE -- One of the cool things about being Bill Gates is that if you are curious about something, you can find smart people who will teach you whatever it is that you want to know. About five years ago Gates decided that he wanted to learn about climate change, so he arranged for two of the world's leading climate scientists, David Keith of the University of Calgary in Alberta, Canada, and Ken Caldeira of the Carnegie Institution, to organize a series of seminars. Since then, Keith and Caldeira have recruited scientists, energy experts, economists, and policy wonks to deliver about a dozen detailed presentations to Gates. He prepares by doing hundreds of pages of reading, some quite technical; the ensuing discussions, which last three or four hours, can be intense. "Bill has the intellectual curiosity of a very bright graduate student," Caldeira says, "but a graduate student whose time you are not supposed to waste."

This is no academic exercise. Gates has been convinced that the risk of global warming is worse than most people think. He can see that the world's governments have failed to curb the emissions caused by burning coal, oil, and natural gas. In June 2010 he put together a coalition of business leaders, including GE's (**GE**) Jeff Immelt, to urge Congress to invest more in clean-energy research, but **that's not happening**.

So the Microsoft (**MSFT**) billionaire and philanthropist has stepped into the breach to become the world's leading funder of research into geoengineering -- deliberate, large-scale interventions in the earth's climate system intended to prevent climate change and its repercussions. Since 2007, Gates has given about $4.6 million of his money to Caldeira and Keith for geoengineering research. Intellectual Ventures, a private company funded in part by Gates, has explored such technologies as building an 18-mile-long hose, tethered by balloons, that would spray tiny particles into the stratosphere to block the sun's rays. Gates has even attached his name to a patent application for ocean-churning technology designed to sap the strength of hurricanes, which appear to be getting fiercer because of global warming.

Unlike **Gates' other passions** -- improving the health of the global poor or reforming America's schools -- geoengineering is scary and maybe even a little nuts. (Or a lot nuts: Some enthusiasts talk about exploding nuclear weapons on the moon to shift its orbit to block more of the sun's rays.) The idea isn't new. The first White House report to talk about global warming said that "deliberately bringing about countervailing climatic change," i.e., geoengineering, should "be thoroughly explored." That was back in 1965. But people are paying more attention now because efforts to curb greenhouse gas emissions are failing, miserably. Despite the UN climate negotiations and the Kyoto Protocol, the growth of solar and **wind power**, and all the talk about the Prius and the curly light bulb, global emissions have risen by 40% -- yes, 40% -- since 1990.

The best-known set of geoengineering technologies fall under an umbrella (pun intended) known as solar radiation management. They are designed to shield the earth from sunlight by injecting particles into the stratosphere or spraying seawater into marine clouds. The trouble is, such planetary-scale tinkering would be bound to have side effects. "The concern, really, is the unknown unknowns," says David Keith. Besides, the governance problems would be daunting. Which nations would get to decide how to cool the planet? Who would control the global thermostat?

Lately another approach to cooling the planet, with far fewer risks, has attracted the attention of a handful of prominent scientists and several wealthy investors, Gates among them. It's a straightforward, albeit audacious, way to deal with the threat of global warming: Build many thousands of big machines to remove carbon dioxide from the air.

Three startup companies are working on capturing carbon dioxide (CO_2) from the air. Carbon Engineering is run by Keith, an MIT-educated physicist, out of offices in Calgary, the nerve center of Canada's oil and gas industry. Gates is an investor, as is his friend Jabe Blumenthal, a former Microsoft executive who is passionate about climate issues. So is N. Murray Edwards, an oil and gas billionaire whose company, Canadian Natural Resources (**CNQ**), extracts oil from Alberta's tar sands.

Global Thermostat, another startup, was formed by two Columbia University professors: Peter Eisenberger, a physicist who founded Columbia's Earth Institute and formerly ran research labs for Bell Labs and Exxon (**XOM**), and Graciela Chichilnisky, an economist, mathematician, and entrepreneur who helped create the world's first carbon-trading markets. Their primary backer is Edgar Bronfman Jr., the Warner Music CEO and heir to the Seagram's fortune. At SRI International, a well-regarded Silicon Valley research institute, Global Thermostat has built a small demonstration plant that today is sucking carbon dioxide from the air.

Finally, there's Kilimanjaro Energy, which was started by another Columbia professor, Klaus Lackner, and initially financed with $8 million from Gary Comer, the founder of Lands' End. An avid sailor and philanthropist, Comer grew concerned about climate change after he sailed a yacht through the normally ice-bound Northwest Passage in 2001. (Comer donated $50 million more for climate change research before his death in 2006.) Last year Kilimanjaro raised another $3.5 million in venture funding.

These supersmart Ph.D.s and their billionaire backers started their companies because they were worried about the threat of global warming. But as they dug into the question of what to do with all the carbon dioxide they want to mop from the air, the entrepreneurs stumbled onto what they say is a big business opportunity. Like some other forms of waste, they say, CO_2 has value. Carbon can be combined with hydrogen to make gasoline or diesel fuels, eventually replacing oil. "If we close the carbon cycle," Eisenberger says, "we can do hydrocarbons forever."

No one doubts that carbon capture is technically feasible. The chemistry is so simple that a child can do it, as we'll see. The questions that these companies face are all about cost. For their businesses to work anytime soon, they will need to drive the cost of pulling carbon out of the air well below $100 per ton of CO_2 and most likely below $50 per ton.

Many scientists think carbon capture will cost far more, as much as $600 a ton, although no one really knows because the first commercial-scale carbon-capture machine is years away from being built. The startup companies say they have found ways to bring costs down, of course, but if they do, and if they can scale up to a massive level -- there's no other way of having a significant climate impact -- they'll face the problem of what to do with all that carbon dioxide. Use it to extract oil and gas from the ground? Feed it to algae? Make fizzy drinks? Dry ice? Turn it into low-carbon fuels? Or bury it?

Well, actually, all of the above. In fact, there's substantial unmet demand for CO_2 at prices that can top $100 a ton. There just might be a real business here.

Pulling CO_2 out of the air

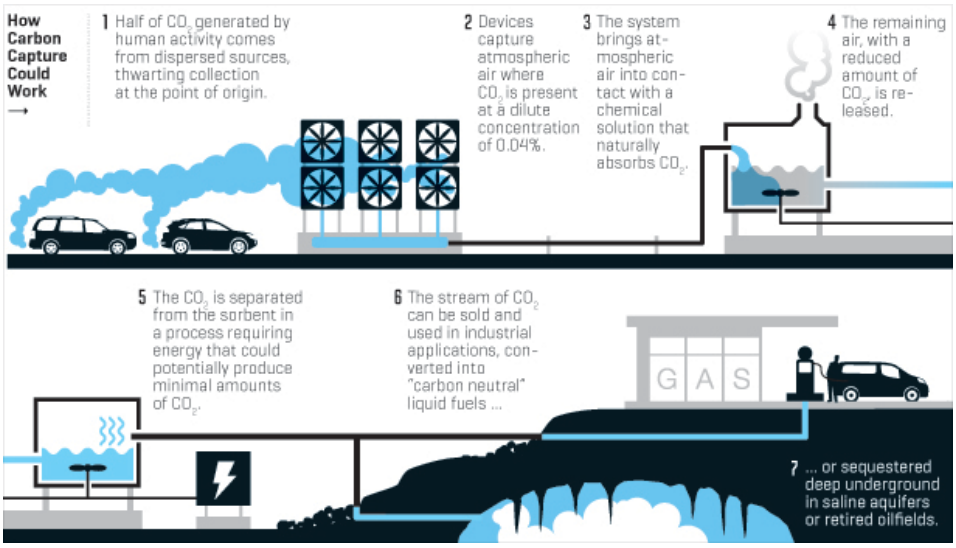
The first scientist to think seriously about capturing carbon dioxide from the air was Klaus Lackner, a German-educated physicist who worked at Los Alamos National Laboratory in New Mexico in the late 1990s. He had been researching technology to capture CO_2 from the flue gas of power plants -- technology in which the U.S. government has invested hundreds of millions of dollars so far, with little to show for it -- and he had begun to think bout how it could be scrubbed from the atmosphere. So when his 12-year-old daughter, Claire, needed an idea for a science project, he asked her, "Why don't you pull CO_2 out of the air?"

Chemical engineers have known for decades that sodium hydroxide, a caustic base also known as lye, will bind with CO_2, an acid, to make carbonates. That's basically how CO_2 is removed from the air in submarines or spaceships. Claire

accomplished the same thing by filling a test tube with a solution of sodium hydroxide, buying a fish-tank pump from a pet store, and running air through the test tube all night. By the next day some of the sodium hydroxide had absorbed CO2, creating a solution of sodium carbonate.

"I was surprised that she pulled this off as well as she did," Lackner recalls, "which made me feel that it could be easier than I thought." (Claire, at it happens, was no ordinary 12-year-old. She became valedictorian of her class at Columbia University, and she's now pursuing a Ph.D. in astrophysics at the Institute for Advanced Studies at Princeton.)

Duly inspired, Klaus Lackner set off on a quest to design a machine to pull CO2 out of the air. He wrote scientific papers on air capture with colleagues at Los Alamos and took a teaching job at Columbia, where he met Gary Comer, the Lands' End founder. In 2004, Comer agreed to finance a startup called Global Research Technologies to study air capture.



GRT set up shop in Tucson, hired a CEO, and developed a device called an air extractor after testing various materials to see which would most efficiently mimic the leaves of trees. Trees absorb CO2 from air, of course, but growing enough of them to have a meaningful impact on the climate would require setting aside vast amounts of arable land.

GRT discovered a sorbent that, when dry, absorbs CO2 from the air and, when moist, releases it. The company began to design machines that will rely on the wind to move air past large, flat filters until they are loaded with CO2; the filters will then be lowered into a closed, humid chamber where the trapped CO2 will be released from the filter, generating air with a 5% to 10% concentration of CO2 This enriched air can be used to feed algae or in greenhouses, or it can be further processed to create a stream of nearly pure CO2.

Last year the company relocated to San Francisco and renamed itself Kilimanjaro Energy. "We're going to try to make fuels, while simultaneously saving the snows of Kilimanjaro," is the way Nathaniel "Ned" David, the company's president, explains it. A Harvard- and Berkeley-trained Ph.D., David, who is 43, was installed as president by Arch Venture Partners, which invested about $3.5 million in Kilimanjaro last summer.

David sums up the company's mission like this: "The single largest waste product made by humanity is CO2. Thirty gigatons a year. It's immensely valuable, and today we just blow it out the tailpipe. What if there were some way to actually capture it, use it, and make money?"

Demand for CO2, it turns out, far exceeds the supply. CO2 has many commercial uses. It provides the bubbles in soda. It's used in greenhouses to make plants grow faster. It's made into dry ice. Companies like Linde and Praxair (**PX**) deliver pure liquid CO2 to customers in the U.S. for between $100 and $200 per ton.

The greatest demand for CO2 comes from the oil industry. Oil companies inject CO2 into reservoirs to squeeze out stranded oil, a proven technology called enhanced oil recovery, or EOR. The U.S. government estimates that state-of-the-

art EOR with carbon dioxide could add an astounding 89 billion barrels of oil to the recoverable oil resources of the U.S. That's more than four times current proven reserves.

Today oil companies are operating about 114 EOR projects, and they pay as much as $20 to $40 per ton of CO2, depending on the price of oil and how far CO2 has to be shipped via pipeline. About three-fourths of the CO2 comes from natural deposits, and the rest is waste from coal, ethanol, and chemical plants. "The single largest deterrent to expanding production from EOR today is the lack of large volumes of reliable and affordable CO2," says Tracy Evans, president of Denbury Resources (**DNR**), an oil company based in Plano, Texas, that specializes in enhanced oil recovery.

The business opportunity is immense, Ned David argues. "The prize is nearly 100 billion barrels of U.S. oil if you can economically capture CO2 from air," he says. "That's $10 trillion of oil, or about 14 years of U.S. oil independence if you don't import a single drop."

But what about those snows of Kilimanjaro? As David explains it, the CO2 used to extract the oil will be sequestered underground, thereby offsetting some of the emissions generated when the oil is burned. Oil recovered that way would have about half the carbon footprint of conventional petroleum. That's the short-term business plan for the company -- generating lower-carbon transportation fuels.

In the long run, as the costs of carbon capture come down and oil reserves are depleted, Kilimanjaro's technology could be used to feed CO2 to algae to make clean biofuels. David knows algae. He helped start **Sapphire Energy, an algae company**, and it was a desire to discover new sources of CO2 that led him to Lackner. "Algae is the most efficient creature for making fuels, and it can't harvest enough CO2 from the atmosphere," he says. Capturing carbon from the air to feed algae makes possible, at least in theory, a closed-cycle fuel -- one in which the CO2 released when the fuel is burned is offset by the CO2 absorbed when it is produced. "And these fuels won't run out," David says.

Two tons of CO2 a day

When they're not teaching at Columbia, Peter Eisenberger and Graciela Chichilnisky retreat to a glass-walled home perched on a cliff above the Pacific Ocean in Mendocino County, Calif. Waves crash below them, and hiking trails run through a redwood forest behind the house. There's not another dwelling, road, or person in sight.

"The Bambi view of nature is the wrong view," Eisenberger tells me as we settle in for a long conversation on his porch, looking at the ocean below. "On a longer time scale, nature is very violent. It operates by creation through disruption -- asteroid impacts, super-volcanoes, giant tsunamis that totally reset things." These disruptions created beautiful places like the Mendocino coast or the Grand Canyon. "There's this whole correlation in nature between violence and beauty," Eisenberger says. He pooh-poohs the idea of preserving the earth in its "natural state" because there's no such thing. "If we just leave nature alone, nature will not leave us alone," he says. "We should manage nature." This, of course, is what **Global Thermostat is all about**.

Global Thermostat's demonstration plant at SRI International, the Silicon Valley research institute

Eisenberger, who is 70, has devoted much of his life to energy issues. He led a renewable-energy lab for Exxon in the 1980s, where he became enamored of solar thermal technology; he continued to work on solar thermal after becoming a professor, first at Princeton and now at Columbia. Chichilnisky, who grew up in Argentina, is his friend and business partner. After earning Ph.D.s in math and economics, she pioneered the idea that governments should pursue "sustainable development," as opposed to just maximizing GDP; she also wrote the plan for the European Union carbon market that came out of the Kyoto climate talks.

Eisenberger and Chichilnisky both have a knack for spotting young talent. He hired a young **Steven Chu** as a researcher at Bell Labs and told the future Nobel Prize winner not to be content with anything less than "starting a new field," Chu wrote in his autobiography. She gave **Jeff Bezos** his first job out of college at Fitel, a global financial communications network that she started and

sold to a Japanese firm. Global Thermostat is a family affair: Peter's son, Harvard-trained lawyer and clean-tech entrepreneur Nicholas Eisenberger, Graciela's daughter, Natasha Chichilnisky, and Edgar Bronfman's son, Benjamin, all advise the firm.

Global Thermostat has found a way to use chemicals known as amines to bind with CO2 from the air; the CO2 is then separated from the amines in a process that uses low-temperature heat. Relying on low-temperature heat keeps costs down because it is widely available at little or no cost as a waste product from power plants or energy-intensive factories. Global Thermostat has retained Carmagen Engineering, a New Jersey firm led by former Exxon engineers, to design its carbon-capture machines, which are envisioned as tall, narrow structures through which air flows. Corning helped the company develop honeycomb-like structures called monoliths on which the carbon is trapped, and BASF is working to develop the required sorbents.

Global Thermostat opened a demonstration plant last October at SRI International. It captures about two tons of CO2 a day; a commercial module, which is the next step, would capture four to five tons a day. A midsize car emits about six tons of CO2 per year.

Summit Power, an established developer of power plants, is considering using Global Thermostat's process in conjunction with a "clean coal" project in Texas that has been awarded $450 million in grants and loans from the U.S. Department of Energy. "We believe that GT has a really great promise of being able to capture CO2 at an economical price per ton," says Eric Redman, Summit Power's president. Global Thermostat is also talking with a Chinese partner about building a pilot plant in China.

Eisenberger and Chichilnisky say they have even bigger things in mind: They want to make gasoline from air and water and the sun. Yes, you read that right. Global Thermostat has formed a joint venture with a startup that they won't name that claims to have found a way to produce hydrogen from water at a lower cost than was previously possible. That's potentially significant because hydrogen extracted from water can be combined with CO2 captured from the air to make renewable, low-carbon transportation fuels, and the process can be powered by solar energy. "It has enormous potential to become a transformative technology," Eisenberger says. Every country in the world could become an oil producer.

Hydrocarbons without Big Oil

Carbon capture on a scale that matters requires thinking big. Building the coal and gas plants, factories, cars, trucks, planes, and ships that have delivered more than a trillion tons of CO2 into the atmosphere has cost many billions of dollars and taken more than a century. Something comparable will be needed to get the carbon out. "If air capture is going to succeed," David Keith says, "it's going to take industrial might." It will also take time: "There's no way you can do a useful amount of carbon dioxide removal in less than a third of a century or maybe half a century."

For Keith, who is 47, the climate-change issue is personal; it threatens places close to his heart. As a young man he spent four months with a biologist tracking walruses on a small island north of the Arctic Circle; while he was there he learned, via short-wave radio, that he'd been accepted to graduate school at MIT. He has returned to the high Arctic for three long ski trips and a kayaking trip, shutting down his cellphone and Internet access for weeks at a time. "I love big wilderness," Keith says.

A prominent climate scientist and early advocate of research into geoengineering, Keith formed Carbon Engineering in 2009 with $3.5 million from Gates and other private investors and $2.5 million in Canadian government grants.

Carbon Engineering is designing a standalone plant that will be powered by natural gas and produce high-pressure CO2. The company, which has eight full-time employees, is drawing upon established technologies used in cooling towers, sewage-treatment plants, and the pulp and paper industry. "This is a big, ugly industrial process that uses at almost every step hardware you can buy commercially today," Keith says. By relying upon proven hardware, Keith hopes to limit technical risks and drive down costs.

Carbon Engineering's business model revolves around what Keith describes as "physical carbon arbitrage." The company plans to build its first carbon-capture plants in places where there is cheap gas, cheap labor, cheap land, and, ideally,

strong demand for CO2. "If we can find all those at once," he says, "we're printing money." That's unlikely, but there are places in the Middle East where stranded gas -- meaning gas not connected to a pipeline -- is very cheap, and oil companies will pay $50 per ton or more, depending on oil prices, for CO2 for enhanced oil recovery.

Like Global Thermostat, Keith envisions carbon-capture plants built in the desert that would be powered by solar energy. They could combine the captured CO2 with manufactured hydrogen to make gasoline or diesel fuels -- carbon-neutral hydrocarbons for cars, trucks, ships, or planes. The product, he says, would be a "hydrocarbon fuel that has all the benefits of hydrocarbons -- energy density and compatibility with the existing infrastructure -- but is not coupled to the oil business." In August, Carbon Engineering began operating a small prototype plant.

A rendering of Carbon Engineering's "slab" air contactor, designed to ingest air and remove CO2 from it

Eyes on the prize

On a February morning in London in 2007, Sir Richard Branson and Al Gore, flanked by scientists and environmental activists, announced the **Virgin Earth Challenge**. They promised to award a $25 million prize to whoever can come up with a commercially viable plan to remove greenhouse gases from the atmosphere.

Said Branson: "Something radical has got to be done to turn back the tide of global warming."

Four years and 2,600 written submissions later, the prize remains unclaimed -- but Carbon Engineering, Global Thermostat, and Kilimanjaro Energy are among a half-dozen finalists.

I call Alan Knight, a geologist who is director of the Earth Challenge, to ask whether four years of thinking about negative-emission technologies have made him more or less optimistic about their practicality. He understands business as well as science, having worked as an executive at SABMiller and the Kingfisher Group, a big British retailer.

He told me that he's come to believe that carbon capture is an important technology, and that the work being done by the startups is "very exciting and very original." He is going to provide them incentives to work together. "We don't want to create just one winner and make the rest losers," he told me. "We would like them to act as a community."

Whether carbon capture will eventually work, at scale and at an acceptable cost, is impossible to know. But it's time to find out. As Knight put it, "We shouldn't give up. If anything, we should be giving these crazy scientists more support."

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The Ash Cloud Defense Shield
In a TEDTalk from 2007, environmental scientist Davivd Keith proposes a controversial solution to climate change.
Video courtesy of TEDTalks, TED.com


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