THE NEW YORKER

ANNALS OF SCIENCE NOVEMBER 20, 2017 ISSUE

CAN CARBON-DIOXIDE REMOVAL SAVE THE WORLD?

CO_2 could soon reach levels that, it's widely agreed, will lead to catastrophe.

By Elizabeth Kolbert

Audio: *Listen to this story. To hear more feature stories, download the Audm app for your iPhone.*

Carbon Engineering, a company owned in part by Bill Gates, has its headquarters on a spit of land that juts into Howe Sound, an hour north of Vancouver. Until recently, the land was a toxic-waste site, and the company's equipment occupies a long, barnlike building that, for many years, was used to process contaminated water. The offices, inherited from the business that poisoned the site, provide a spectacular view of Mt. Garibaldi, which rises to a snow-covered point, and of the Chief, a granite monolith that's British Columbia's answer to El Capitan. To protect the spit against rising sea levels, the local government is planning to cover it with a layer of fill six feet deep. When that's done, it's hoping to sell the site for luxury condos.

of pure calcium carbonate.

Corless and his team are engaged in a project that falls somewhere between toxic-waste cleanup and alchemy. They've devised a process that allows them, in effect, to suck carbon dioxide out of the air. Every day at the plant, roughly a ton of CO_2 that had previously floated over Mt. Garibaldi or the Chief is converted into calcium carbonate. The pellets are subsequently heated, and the gas is forced off, to be stored in cannisters. The calcium can then be recovered, and the process run through all over again.

"If we're successful at building a business around carbon removal, these are trillion-dollar markets," Corless told me.

This past April, the concentration of carbon dioxide in the atmosphere reached a record four hundred and ten parts per million. The amount of CO_2 in the air now is probably greater than it's been at any time since the mid-Pliocene, three and a half million years ago, when there was a lot less ice at the poles and sea levels were sixty feet higher. This year's record will be surpassed next year, and next year's the year after that. Even if every country fulfills the pledges made in the Paris climate accord—and the United States has said that it doesn't intend to—carbon dioxide could soon reach levels that, it's widely agreed, will lead to catastrophe, assuming it hasn't already done so.

Carbon-dioxide removal is, potentially, a trillion-dollar enterprise because it offers a way not just to slow the rise in CO_2 but to reverse it. The process is sometimes referred to as "negative emissions": instead of adding carbon to the air, it subtracts it. Carbon-removal plants could be built anywhere, or everywhere. Construct enough of them and, in theory at least, CO_2 emissions could continue unabated and still we could avert calamity. Depending on how you look at things, the technology represents either the ultimate insurance policy or the ultimate moral hazard.

Carbon Engineering is one of a half-dozen companies vying to prove that carbon removal is feasible. Others include Global Thermostat, which is based in New York, and Climeworks, based near Zurich. Most of these owe their origins to the ideas of a physicist named Klaus Lackner, who now works at Arizona State University, in Tempe, so on my way home from British Columbia I took a detour to visit him. It was July, and on the day I arrived the temperature in the city reached a hundred and twelve degrees. When I got to my hotel, one of the first things I noticed was a dead starling lying, feet up, in the parking lot. I wondered if it had died from heat exhaustion.

Lackner, who is sixty-five, grew up in Germany. He is tall and lanky, with a fringe of gray hair and a prominent forehead. I met him in his office at an institute he runs, the Center for Negative Carbon Emissions. The office was bare, except for a few *New Yorker* cartoons on the theme of nerd-dom, which, Lackner told me, his wife had cut out for him. In one, a couple of scientists stand in front of an enormous whiteboard covered in equations. “The math is right,” one of them says. “It’s just in poor taste.”

In the late nineteen-seventies, Lackner moved from Germany to California to study with George Zweig, one of the discoverers of quarks. A few years later, he got a job at Los Alamos National Laboratory. There, he worked on fusion. “Some of the work was classified,” he said, “some of it not.”

Fusion is the process that powers the stars and, closer to home, thermonuclear bombs. When Lackner was at Los Alamos, it was being touted as a solution to the world’s energy problem; if fusion could be harnessed, it could generate vast amounts of carbon-free power using isotopes of hydrogen. Lackner became convinced that a fusion reactor was, at a minimum, decades away. (Decades later, it’s generally agreed that a workable reactor is still decades away.) Meanwhile, the globe’s growing population would demand more and more energy, and this demand would be met, for the most part, with fossil fuels.

“I realized, probably earlier than most, that the claims of the demise of fossil fuels were greatly exaggerated,” Lackner told me. (In fact, fossil fuels currently provide about eighty per cent of the world’s energy. Proportionally, this figure hasn’t changed much since the mid-eighties, but, because global energy use has nearly doubled, the amount of coal, oil, and natural gas being burned today is almost two times greater.)

One evening in the early nineties, Lackner was having a beer with a friend, Christopher Wendt, also a physicist. The two got to wondering why, as Lackner put it to me, "nobody's doing these really crazy, big things anymore." This led to more questions and more conversations (and possibly more beers).

Eventually, the two produced an equation-dense paper in which they argued that self-replicating machines could solve the world's energy problem and, more or less at the same time, clean up the mess humans have made by burning fossil fuels. The machines would be powered by solar panels, and as they multiplied they'd produce more solar panels, which they'd assemble using elements, like silicon and aluminum, extracted from ordinary dirt. The expanding collection of panels would produce ever more power, at a rate that would increase exponentially. An array covering three hundred and eighty-six thousand square miles—an area larger than Nigeria but, as Lackner and Wendt noted, "smaller than many deserts"—could supply all the world's electricity many times over.

This same array could be put to use scrubbing carbon dioxide from the atmosphere. According to Lackner and Wendt, the power generated by a Nigeria-size solar farm would be enough to remove all the CO_2 emitted by humans up to that point within five years. Ideally, the CO_2 would be converted to rock, similar to the white sand produced by Carbon Engineering; enough would be created to cover Venezuela in a layer a foot and a half deep. (Where this rock would go the two did not specify.)

Lackner let the idea of the self-replicating machine slide, but he became more and more intrigued by carbon-dioxide removal, particularly by what's become known as "direct air capture."

"Sometimes by thinking through this extreme end point you learn a lot," he said. He began giving talks and writing papers on the subject. Some scientists decided he was nuts, others that he was a visionary. "Klaus is, in fact, a genius," Julio Friedmann, a former Principal Deputy Assistant Secretary of Energy and an expert on carbon management, told me.

In 2000, Lackner received a job offer from Columbia University. Once in New York, he pitched a plan for developing a carbon-sucking technology to Gary Comer, a founder of Lands' End. Comer brought to the meeting his investment adviser, who quipped that Lackner wasn't looking for venture capital so much as "adventure capital." Nevertheless, Comer offered to put up five million dollars. The new company was called Global Research Technologies, or G.R.T. It got as far as building a small prototype, but just as it was looking for new investors the financial crisis hit.

"Our timing was exquisite," Lackner told me. Unable to raise more funds, the company ceased operations. As the planet continued to warm, and carbon-dioxide levels continued to climb, Lackner came to believe that, unwittingly, humanity had already committed itself to negative emissions.

"I think that we're in a very uncomfortable situation," he said. "I would argue that if technologies to pull CO_2 out of the environment fail then we're in deep trouble."

Lackner founded the Center for Negative Carbon Emissions at A.S.U. in 2014. Most of the equipment he dreams up is put together in a workshop a few blocks from his office. The day I was there, it was so hot outside that even the five-minute walk to the workshop required staging. Lackner delivered a short lecture on the dangers of dehydration and handed me a bottle of water.

In the workshop, an engineer was tinkering with what looked like the guts of a foldout couch. Where, in the living-room version, there would have been a mattress, in this one was an elaborate array of plastic ribbons. Embedded in each ribbon was a powder made from thousands upon thousands of tiny amber-colored beads. The beads, Lackner explained, could be purchased by the truckload; they were composed of a resin normally used in water treatment to remove chemicals like nitrates. More or less by accident, Lackner had discovered that the beads could be repurposed. Dry, they'd absorb carbon dioxide. Wet, they'd release it. The idea was to expose the ribbons to Arizona's thirsty air, and then fold the device into a sealed container filled with water. The CO_2 that had been captured by the powder in the dry phase would be released in the wet phase; it could then be piped out of the container, and the whole process re-started, the couch folding and unfolding over and over again.

Lackner has calculated that an apparatus the size of a semi trailer could remove a ton of carbon dioxide per day, or three hundred and sixty-five tons a year. The world's cars, planes, refineries, and power plants now produce about thirty-six billion tons of CO_2 annually, so, he told me, "if you built a hundred million trailer-size units you could actually keep up with current emissions." He acknowledged that the figure sounded daunting. But, he noted, the iPhone has been around for only a decade or so, and there are now seven hundred million in use. "We are still very early in this game," he said.

The way Lackner sees things, the key to avoiding "deep trouble" is thinking differently. "We need to change the paradigm," he told me. Carbon dioxide should be regarded the same way we view other waste products, like sewage or garbage. We don't expect people to stop producing waste. ("Rewarding people for going to the bathroom less would be nonsensical," Lackner has observed.) At the same time, we don't let them shit on the sidewalk or toss their empty yogurt containers into the street.

"If I were to tell you that the garbage I'm dumping in front of your house is twenty per cent less this year than it was last year, you would still think I'm doing something intolerable," Lackner said.

One of the reasons we've made so little progress on climate change, he contends, is that the issue has acquired an ethical charge, which has polarized people. To the extent that emissions are seen as bad, emitters become guilty. "Such a moral stance makes virtually everyone a sinner, and makes hypocrites out of many who are concerned about climate change but still partake in the benefits of modernity," he has written. Changing the paradigm, Lackner believes, will change the conversation. If CO_2 is treated as just another form of waste, which has to be disposed of, then people can stop arguing about whether it's a problem and finally start doing something.

Carbon dioxide was "discovered," by a Scottish physician named Joseph Black, in 1754. A decade later, another Scotsman, James Watt, invented a more efficient steam engine, ushering in what is now called the age of industrialization but which future generations may dub the age of emissions. It is likely that by the end of the nineteenth century human activity had raised the average temperature of the earth by a tenth of a degree Celsius (or nearly two-tenths of a degree Fahrenheit).

As the world warmed, it started to change, first gradually and then suddenly. By now, the globe is at least one degree Celsius (1.8 degrees Fahrenheit) warmer than it was in Black's day, and the consequences are becoming ever more apparent. Heat waves are hotter, rainstorms more intense, and droughts drier. The wildfire season is growing longer, and fires, like the ones that recently ravaged Northern California, more numerous. Sea levels are rising, and the rate of rise is accelerating. Higher sea levels exacerbated the damage from Hurricanes Harvey, Irma, and Maria, and higher water temperatures probably also made the storms more ferocious. "Harvey is what climate change looks like," Eric Holthaus, a meteorologist turned columnist, recently wrote.

Meanwhile, still more warming is locked in. There's so much inertia in the climate system, which is as vast as the earth itself, that the globe has yet to fully adjust to the hundreds of billions of tons of carbon dioxide that have been added to the atmosphere in the past few decades. It's been calculated that to equilibrate to current CO_2 levels the planet still needs to warm by half a degree. And every ten days another billion tons of carbon dioxide are released. Last month, the World Meteorological Organization announced that the concentration of carbon dioxide in the atmosphere jumped by a record amount in 2016.

No one can say exactly how warm the world can get before disaster—the inundation of low-lying cities, say, or the collapse of crucial ecosystems, like coral reefs—becomes inevitable. Officially, the threshold is two degrees Celsius (3.6 degrees Fahrenheit) above preindustrial levels. Virtually every nation signed on to this figure at a round of climate negotiations held in Cancún in 2010.

Meeting in Paris in 2015, world leaders decided that the two-degree threshold was too high; the stated aim of the climate accord is to hold "the increase in the global average temperature to well below 2°C" and to try to limit it to 1.5°C. Since the planet has already warmed by one degree and, for all practical purposes, is committed to another half a degree, it would seem impossible to meet the latter goal and nearly impossible to meet the former. And it *is* nearly impossible, unless the world switches course and instead of just adding CO_2 to the atmosphere also starts to remove it.

The extent to which the world is counting on negative emissions is documented by the latest report of the Intergovernmental Panel on Climate Change, which was published the year before Paris. To peer into the future, the I.P.C.C. relies on computer models that represent the world's energy and climate systems as a tangle of equations, and which can be programmed to play out different "scenarios." Most of the scenarios involve temperature increases of two, three, or even four degrees Celsius—up to just over seven degrees Fahrenheit—by the end of this century. (In a recent paper in the *Proceedings of the National Academy of Sciences*, two climate scientists—Yangyang Xu, of Texas A. & M., and Veerabhadran Ramanathan, of the Scripps Institution of Oceanography—proposed that warming greater than three degrees Celsius be designated as "catastrophic" and warming greater than five degrees as "unknown??" The "unknown??" designation, they wrote, comes "with the understanding that changes of this magnitude, not experienced in the last 20+ million years, pose existential threats to a majority of the population.")

When the I.P.C.C. went looking for ways to hold the temperature increase under two degrees Celsius, it found the math punishing. Global emissions would have to fall rapidly and dramatically—pretty much down to zero by the middle of this century. (This would entail, among other things, replacing most of the world's power plants, revamping its agricultural systems, and eliminating gasoline-powered vehicles, all within the next few decades.) Alternatively, humanity could, in effect, go into hock. It could allow CO_2 levels temporarily to exceed the two-degree threshold—a situation that's become known as "overshoot"—and then, via negative emissions, pull the excess CO_2 out of the air.

The I.P.C.C. considered more than a thousand possible scenarios. Of these, only a hundred and sixteen limit warming to below two degrees, and of these a hundred and eight involve negative emissions. In many below-two-degree scenarios, the quantity of negative emissions called for reaches the same order of magnitude as the "positive" emissions being produced today.

"The volumes are outright crazy," Oliver Geden, the head of the E.U. research division of the German Institute for International and Security Affairs, told me. Lackner said, "I think what the I.P.C.C. really is saying is 'We tried lots and lots of scenarios, and, of the scenarios which stayed safe, virtually every one needed some magic touch of a negative emissions. If we didn't do that, we ran into a brick wall.' "

Pursued on the scale envisioned by the I.P.C.C., carbon-dioxide removal would yield at first tens of billions and soon hundreds of billions of tons of CO_2, all of which would have to be dealt with. This represents its own supersized challenge. CO_2 can be combined with calcium to produce limestone, as it is in the process at Carbon Engineering (and in Lackner's self-replicating-machine scheme). But the necessary form of calcium isn't readily available, and producing it generally yields CO_2, a self-defeating prospect. An alternative is to shove the carbon back where it came from, deep underground.

"If you are storing CO_2 and your only purpose is storage, then you're looking for a package of certain types of rock," Sallie Greenberg, the associate director for energy, research, and development at the Illinois State Geological Survey, told me. It was a bright summer day, and we were driving through the cornfields of Illinois's midsection. A mile below us was a rock formation known as the Eau Claire Shale, and below that a formation known as the Mt. Simon Sandstone. Together with a team of drillers, engineers, and geoscientists, Greenberg has spent the past decade injecting carbon dioxide into this rock "package" and studying the outcome. When I'd proposed over the phone that she show me the project, in Decatur, she'd agreed, though not without hesitation.

"It isn't sexy," she'd warned me. "It's a wellhead."

Our first stop was a building shaped like a ski chalet. This was the National Sequestration Education Center, a joint venture of the Illinois geological survey, the U.S. Department of Energy, and Richland Community College. Inside were classrooms, occupied that morning by kids making lanyards, and displays aimed at illuminating the very dark world of carbon storage. One display was a sort of oversized barber pole, nine feet tall and decorated in bands of tan and brown, representing the various rock layers beneath us. A long arrow on the side of the pole indicated how many had been drilled through for Greenberg's carbon-storage project; it pointed down, through the New Albany Shale, the Maquoketa Shale, and so on, all the way to the floor.

The center's director, David Larrick, was on hand to serve as a guide. In addition to schoolkids, he said, the center hosted lots of community groups, like Kiwanis clubs.

"This is very effective as a visual," he told me, gesturing toward the pole. Sometimes farmers were concerned about the impact that the project could have on their water supply. The pole showed that the CO_2 was being injected more than a mile below their wells.

"We have had overwhelmingly positive support," he said. While Greenberg and Larrick chatted, I wandered off to play an educational video game. A cartoon figure in a hard hat appeared on the screen to offer factoids such as "The most efficient method of transport of CO_2 is by pipeline."

"Transport CO_2 to earn points!" the cartoon man exhorted.

After touring the center's garden, which featured grasses, like big bluestem, that would have been found in the area before it was plowed into cornfields, Greenberg and I drove on. Soon we passed through the gates of an enormous Archer Daniels Midland plant, which rose up out of the fields like a small city.

Greenberg explained that the project we were visiting was one of seven funded by the Department of Energy to learn whether carbon injected underground would stay there. In the earliest stage of the project, initiated under President George W. Bush, Greenberg and her colleagues sifted through geological records to find an appropriate test site. What they were seeking was similar to what oil drillers look for—porous stone capped by a layer of impermeable rock—only they were looking not to extract fossil fuels but, in a manner of speaking, to stuff them back in. The next step was locating a ready source of carbon dioxide. This is where A.D.M. came in; the plant converts corn into ethanol, and one of the by-products of this process is almost pure CO_2. In a later stage of the project, during the Obama Administration, a million tons of carbon dioxide from the plant were pumped underground. Rigorous monitoring has shown that, so far, the CO_2 has stayed put.

We stopped to pick up hard hats and went to see some of the monitoring equipment, which was being serviced by two engineers, Nick Malkewicz and Jim Kirksey. It was now lunchtime, so we made another detour, to a local barbecue place. Finally, Greenberg and I and the two men got to the injection site. It was, indeed, not sexy—

just a bunch of pipes and valves sticking out of the dirt. I asked about the future of carbon storage.

"I think the technology's there and it's absolutely viable," Malkewicz said. "It's just a question of whether people want to do it or not. It's kind of an obvious thing."

"We know we can meet the objective of storing CO_2," Greenberg added. "Like Nick said, it's just a matter of whether or not as a society we're going to do it."

When work began on the Decatur project, in 2003, few people besides Klaus Lackner were thinking about sucking CO_2 from the air. Instead, the goal was to demonstrate the feasibility of an only slightly less revolutionary technology—carbon capture and storage (or, as it is sometimes referred to, carbon capture and sequestration).

With C.C.S., the CO_2 produced at a power station or a steel mill or a cement plant is drawn off before it has a chance to disperse into the atmosphere. (This is called "post-combustion capture.") The gas, under very high pressure, is then injected into the appropriate package of rock, where it is supposed to remain permanently. The process has become popularly—and euphemistically—known as "clean coal," because, if all goes according to plan, a plant equipped with C.C.S. produces only a fraction of the emissions of a conventional coal-fired plant.

Over the years, both Republicans and Democrats have touted clean coal as a way to save mining jobs and protect the environment. The coal industry has also, nominally at least, embraced the technology; one industry-sponsored group calls itself the American Coalition for Clean Coal Electricity. Donald Trump, too, has talked up clean coal, even if he doesn't seem to quite understand what the term means. "We're going to have clean coal, really clean coal," he said in March.

Currently, only one power plant in the U.S., the Petra Nova plant, near Houston, uses post-combustion carbon capture on a large scale. Plans for other plants to showcase the technology have been scrapped, including, most recently, the Kemper County plant, in Mississippi. This past June, the plant's owner, Southern Company, announced that it was changing tacks. Instead of burning coal and capturing the carbon, the plant would burn natural gas and release the CO_2.

Experts I spoke to said that the main reason C.C.S. hasn't caught on is that there's no inducement to use it. Capturing the CO_2 from a smokestack consumes a lot of power—up to twenty-five per cent of the total produced at a typical coal-burning plant. And this, of course, translates into costs. What company is going to assume such costs when it can dump CO_2 into the air for free?

"If you're running a steel mill or a power plant and you're putting the CO_2 into the atmosphere, people might say, 'Why aren't you using carbon capture and storage?' " Howard Herzog, an engineer at M.I.T. who for many years ran a research program on C.C.S., told me. "And you say, 'What's my financial incentive? No one's saying I *can't* put it in the atmosphere.' In fact, we've gone backwards in terms of sending signals that you're going to have to restrict it."

But, although C.C.S. has stalled in practice, it has become ever more essential on paper. Practically all below-two-degree warming scenarios assume that it will be widely deployed. And even this isn't enough. To avoid catastrophe, most models rely on a yet to be realized variation of C.C.S., known as BECCS.

BECCS, which stands for "bio-energy with carbon capture and storage," takes advantage of the original form of carbon engineering: photosynthesis. Trees and grasses and shrubs, as they grow, soak up CO_2 from the air. (Replanting forests is a low-tech form of carbon removal.) Later, when the plants rot or are combusted, the carbon they have absorbed is released back into the atmosphere. If a power station were to burn wood, say, or cornstalks, and use C.C.S. to sequester the resulting CO_2, this cycle would be broken. Carbon would be sucked from the air by the green plants and then forced underground. BECCS represents a way to generate negative emissions and, at the same time, electricity. The arrangement, at least as far as the models are concerned, could hardly be more convenient.

"BECCS is unique in that it removes carbon *and* produces energy," Glen Peters, a senior researcher at the Center for International Climate Research, in Oslo, told me. "So the more you consume the more you remove." He went on, "In a sense, it's a dream technology. It's solving one problem while solving the other problem. What more could you want?"

The Center for Carbon Removal doesn't really have an office; it operates out of a co-working space in downtown Oakland. On the day I visited, not long after my trip to Decatur, someone had recently stopped at Trader Joe's, and much of the center's limited real estate was taken up by tubs of treats.

"Open anything you want," the center's executive director, Noah Deich, urged me, with a wave of his hand.

Deich, who is thirty-one, has a broad face, a brown beard, and a knowing sort of earnestness. After graduating from the University of Virginia, in 2009, he went to work for a consulting firm in Washington, D.C., that was advising power companies about how to prepare for a time when they'd no longer be able to release carbon into the atmosphere cost-free. It was the start of the Obama Administration, and that time seemed imminent. The House of Representatives had recently approved legislation to limit emissions. But the bill later died in the Senate, and, as Deich put it, "It's no fun to model the impacts of climate policies nobody believes are going to happen." He switched consulting firms, then headed to business school, at the University of California, Berkeley.

"I came into school with this vision of working for a clean-tech startup," he told me. "But I also had this idea floating around in the back of my head that we're moving too slowly to actually stop emissions in time. So what do we do with all the carbon that's in the air?" He started talking to scientists and policy experts at Berkeley. What he learned shocked him.

"People told me, 'The models show this major need for negative emissions,' " he recalled. " 'But we don't really know how to do that, nor is anyone really thinking about it.' I was someone who'd been in the business and policy world, and I was, like, wait a minute—*what*?"

Business school taught Deich to think in terms of case studies. One that seemed to him relevant was solar power. Photovoltaic cells have been around since the nineteen-fifties, but for decades they were prohibitively expensive. Then the price started to drop, which increased demand, which led to further price drops, to the point where today, in many parts of the world, the cost of solar power is competitive with the cost of power from new coal plants.

“And the reason that it’s now competitive is that governments decided to do lots and lots of research,” Deich said. “And some countries, like Germany, decided to pay a lot for solar, to create a first market. And China paid a lot to manufacture the stuff, and states in the U.S. said, ‘You must consume renewable energy,’ and then consumers said, ‘Hey, how can I buy renewable energy?’ ”

As far as he could see, none of this—neither the research nor the creation of first markets nor the spurring of consumer demand—was being done for carbon removal, so he decided to try to change that. Together with a Berkeley undergraduate, Giana Amador, he founded the center in 2015, with a hundred-and-fifty-thousand-dollar grant from the university. It now has an annual budget of about a million dollars, raised from private donors and foundations, and a staff of seven. Deich described it as a “think-and-do tank.”

“We’re trying to figure out: how do we actually get this on the agenda?” he said.

A compelling reason for putting carbon removal on “the agenda” is that we are already counting on it. Negative emissions are built into the I.P.C.C. scenarios and the climate agreements that rest on them.

But everyone I spoke with, including the most fervent advocates for carbon removal, stressed the huge challenges of the work, some of them technological, others political and economic. Done on a scale significant enough to make a difference, direct air capture of the sort pursued by Carbon Engineering, in British Columbia, would require an enormous infrastructure, as well as huge supplies of power. (Because CO_2 is more dilute in the air than it is in the exhaust of a power plant, direct air capture demands even more energy than C.C.S.) The power would have to be generated emissions-free, or the whole enterprise wouldn’t make much sense.

“You might say it’s against my self-interest to say it, but I think that, in the near term, talking about carbon removal is silly,” David Keith, the founder of Carbon Engineering, who teaches energy and public policy at Harvard, told me. “Because it almost certainly is cheaper to cut emissions now than to do large-scale carbon removal.”

BECCS doesn’t make big energy demands; instead, it requires vast tracts of arable land. Much of this land would, presumably, have to be diverted from food production, and at a time when the global population—and therefore global food demand—is projected to be growing. (It's estimated that to do BECCS on the scale envisioned by some below-two-degrees scenarios would require an area larger than India.) Two researchers in Britain, Naomi Vaughan and Clair Gough, who recently conducted a workshop on BECCS, concluded that "assumptions regarding the extent of bioenergy deployment that is possible" are generally "unrealistic."

For these reasons, many experts argue that even talking (or writing articles) about negative emissions is dangerous. Such talk fosters the impression that it's possible to put off action and still avoid a crisis, when it is far more likely that continued inaction will just produce a larger crisis. In "The Trouble with Negative Emissions," an essay that ran last year in *Science*, Kevin Anderson, of the Tyndall Centre for Climate Change Research, in England, and Glen Peters, of the climate-research center in Oslo, described negative-emissions technologies as a "high-stakes gamble" and relying on them as a "moral hazard par excellence."

We should, they wrote, "proceed on the premise that they will not work at scale."

Others counter that the moment for fretting about the hazards of negative emissions—moral or otherwise—has passed.

"The punch line is, it doesn't matter," Julio Friedmann, the former Principal Deputy Assistant Energy Secretary, told me. "We actually need to do direct air capture, so we need to create technologies that do that. Whether it's smart or not, whether it's optimized or not, whether it's the lowest-cost pathway or not, we know we need to do it."

"If you tell me that we don't know whether our stuff will work, I will admit that is true," Klaus Lackner said. "But I also would argue that nobody else has a good option."

One of the peculiarities of climate discussions is that the strongest argument for any given strategy is usually based on the hopelessness of the alternatives: this approach *must* work, because clearly the others aren't going to. This sort of reasoning rests on a fragile premise—what might be called solution bias. There has to be an answer out there somewhere, since the contrary is too horrible to contemplate.

Early last month, the Trump Administration announced its intention to repeal the Clean Power Plan, a set of rules aimed at cutting power plants' emissions. The plan, which had been approved by the Obama Administration, was eminently achievable. Still, according to the current Administration, the cuts were too onerous. The repeal of the plan is likely to result in hundreds of millions of tons of additional emissions.

A few weeks later, the United Nations Environment Programme released its annual Emissions Gap Report. The report labelled the difference between the emissions reductions needed to avoid dangerous climate change and those which countries have pledged to achieve as "alarmingly high." For the first time, this year's report contains a chapter on negative emissions. "In order to achieve the goals of the Paris Agreement," it notes, "carbon dioxide removal is likely a necessary step."

As a technology of last resort, carbon removal is, almost by its nature, paradoxical. It has become vital without necessarily being viable. It may be impossible to manage and it may also be impossible to manage without. ♦

This article appears in the print edition of the November 20, 2017, issue, with the headline "Going Negative."

Elizabeth Kolbert has been a staff writer at The New Yorker since 1999. She won the 2015 Pulitzer Prize for general nonfiction for "The Sixth Extinction: An Unnatural History." *Read more »*

CONDÉ NAST