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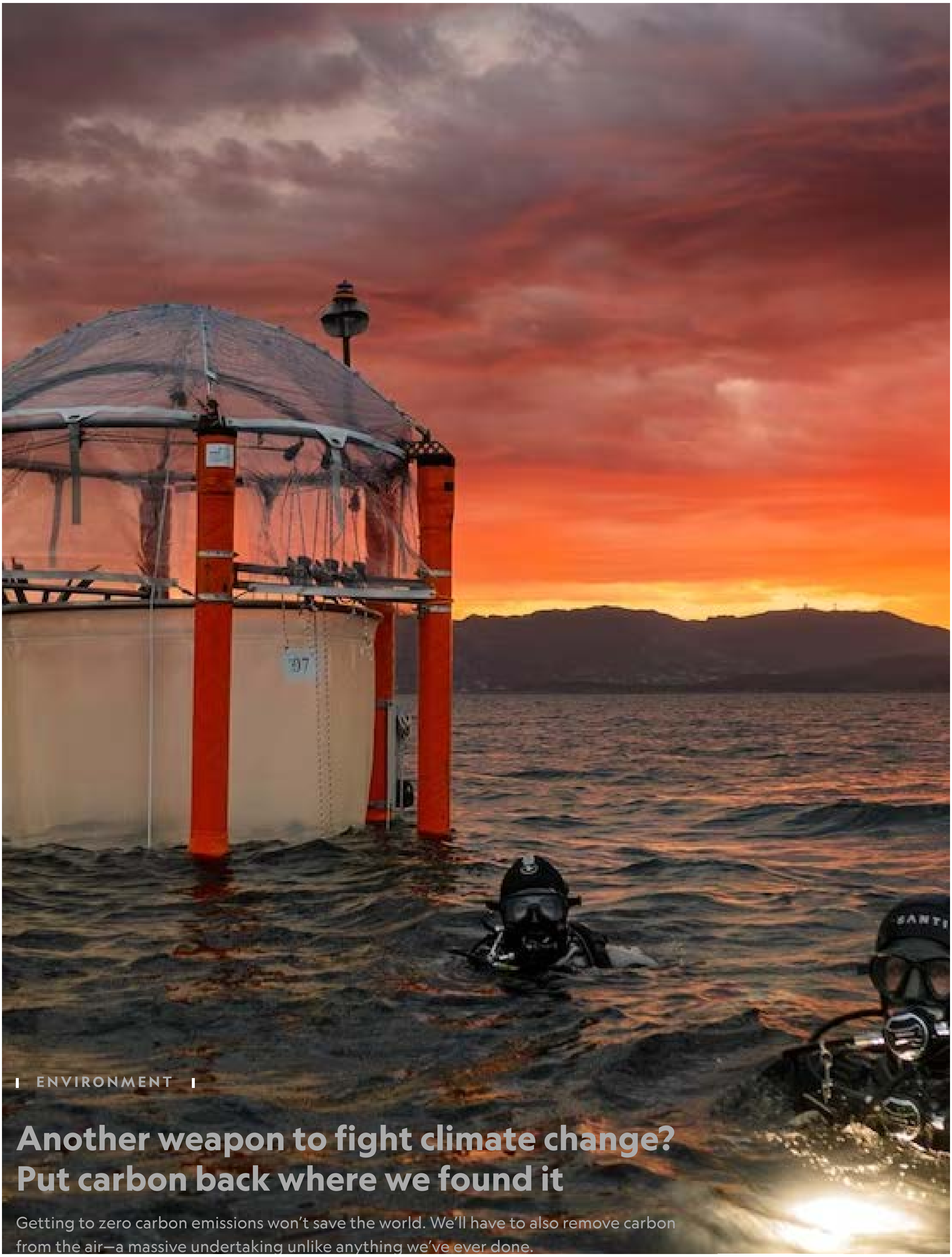

ENVIRONMENT

# Another weapon to fight climate change? Put carbon back where we found it

Getting to zero carbon emissions won't save the world. We'll have to also remove carbon from the air—a massive undertaking unlike anything we've ever done.

Scientists monitor a mesocosm—an experimental enclosure—off the coast of Norway to see how seawater absorbs carbon dioxide from alkaline materials. “The question is, can we significantly speed up that natural process?” says project leader Ulf Riebesell.

BY **SAM HOWE VERHOVEK**

PHOTOGRAPHS AND VIDEO BY **DAVIDE MONTELEONE**

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**Over the past few centuries,** we have dug, chopped, burned, drilled, pumped, stripped, forged, flared, lit, launched, driven, and flown our way to adding 2.4 trillion metric tons of carbon dioxide to Earth’s atmosphere.

That’s as much $CO_2$ as would be emitted annually by 522 billion cars, or 65 cars per person living today.

On a lonely, lunar-like valley 20 miles outside of Reykjavík, Iceland, Edda Aradóttir is on a mission to put it back where it came from.

*12 promising carbon removal strategies*

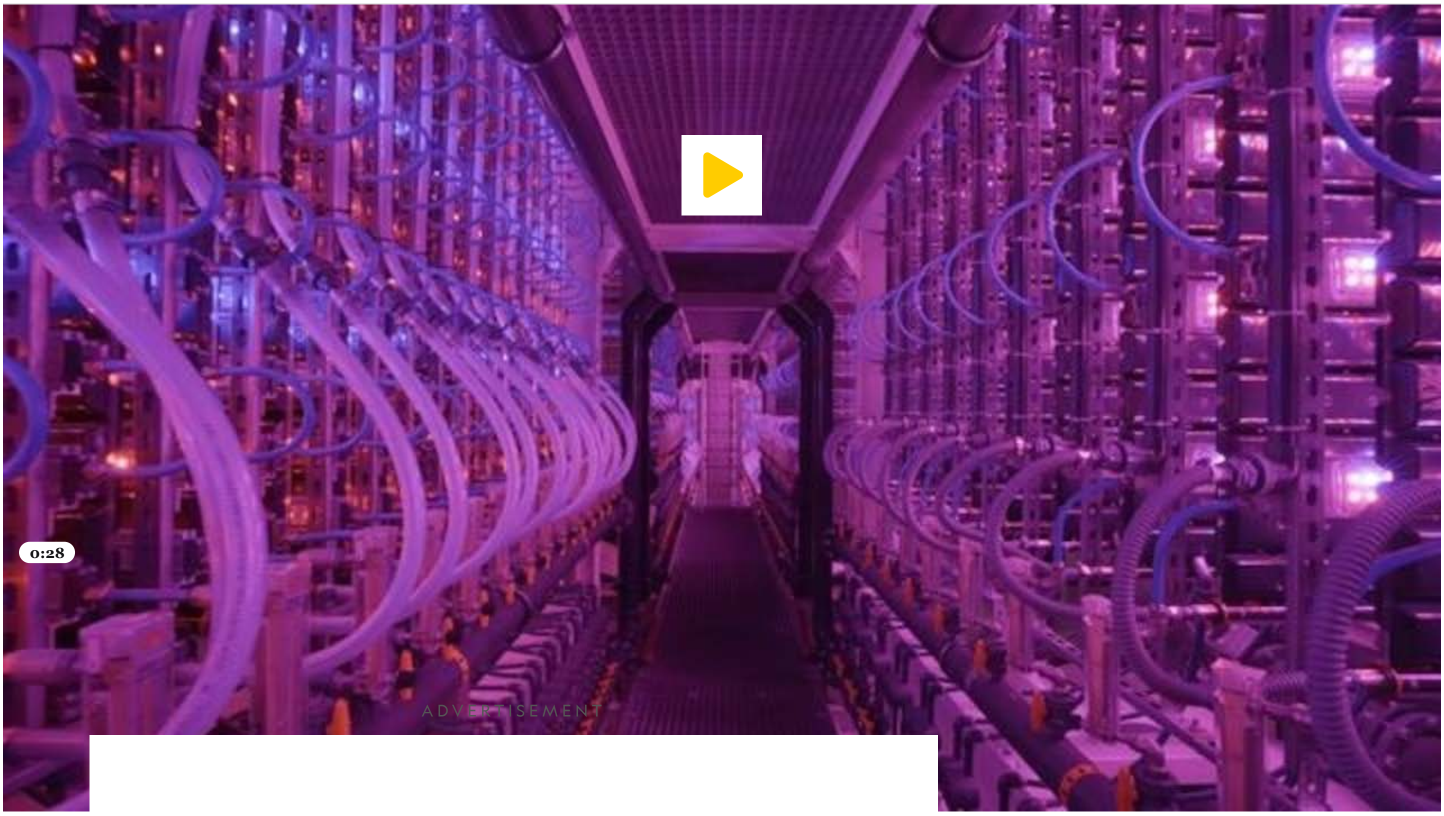
She’s returning a tiny bit of it today but much, much more of it in the years ahead. In sending $CO_2$ deep beneath the surface of the planet, she’s aiming to reverse one of the most consequential acts of human history: the unearthing of massive amounts of subterranean carbon as fossil fuels, the lifeblood of modern civilization but now its bane as well.

She doesn’t have much time. Nor do the rest of us. The extreme weather and record-hot temperatures from climate change are already here—and virtually certain to get worse.

A light attached to a drone illuminates a geodesic aluminum igloo on a massive lava field near Reykjavík in this composite image. Inside, the Icelandic company Carbfix is turning captured carbon dioxide into stone—considered a gold standard for CO2 sequestration, since... **Read More**

Inside an aluminum igloo on this patch of volcanic dirt, Aradóttir—a chemical and reservoir engineer who is chief executive officer of an Icelandic company called Carbfix—shows me how captured $CO_2$ is mixed with water, then fed through an elaborate system of pipes that course downward 2,500 feet or so. There, the dissolved carbon dioxide meets porous basalt, creating a stippling of cream-colored speckles in the igneous rock below.

She hands me a sample core to inspect. All those dots and stripes represent an ambition that is simple but breathtakingly audacious, because minuscule as the amount may be, this particular bit of $CO_2$—plucked from the air, mineralized, and turned to stone—is no longer heating up our planet.






**Scientists and entrepreneurs** like Aradóttir are embarking on ambitious—and sometimes controversial—projects to remove carbon dioxide from ambient air and lock it away. In Arizona, an engineering professor shows me his "mechanical tree," a single one of which he says may someday be able to do the work of a thousand regular trees in capturing and storing $CO_2$. In Australia, a leading oceanographer tells me that seaweed is salvation, if only we'd help it grow in giant aqua-gardens of kelp and wakame that could harbor billions of tons of carbon dioxide. Atop a university building in Zürich, an Uruguayan inventor with a gleam in his eye presents me with a small vial of fuel made from nothing but sunlight and air. That may be the most intriguing of all the forms of carbon capture I've come across, as it suggests we may one day be able to harness carbon in a continuous virtuous cycle of zero-emission energy. Maybe. One day.

What these efforts have in common is that they are geared in the long run to drag downward a number that climate experts agree holds the key to the health of the planet. That number is the atmospheric concentration of carbon dioxide, which for thousands of years had held stable at or a bit below 280 parts per million, until the industrial revolution kicked off in the middle of the 19th century. Today this critical number stands at some 420 parts per million—in other words, the percentage of $CO_2$ in the atmosphere has risen roughly 50 percent since 1850. As it rises, the added levels. Carbon-capture proponents say that their work—to capture the main driver of climate change, radically scaled up in coming decades—will help bring this number down.

**Click here to see 12 promising carbon removal strategies**

EXPLORE



But what all these efforts *also* have in common is that to their many detractors, the very idea of sucking all this carbon out of the air is a diversion from the far more urgent task of radically cutting carbon dioxide emissions to begin with.

More than 500 environmental groups, for instance, have signed a petition urging U.S. and Canadian leaders to “abandon the dirty, dangerous myth of CCS,” or carbon capture and storage, a major form of carbon removal. The petition blasts the concept as “a dangerous distraction driven by the same big polluters who created the climate emergency,” a reference to plans announced by ExxonMobil, Chevron, and other traditional oil giants to jump into the carbon-capture business. It is enraging, critics say, that the forces most responsible for getting us into this global mess now stand to profit from promises that they can clean it up.

The term “moral hazard,” the idea that people will continue to take risks if they believe they’re shielded from the consequences, comes up often in this debate. If policymakers, not to mention average people, start thinking that maybe we have a magic solution for all this troublesome $CO_2$, perhaps they’ll start worrying less about the oil, gas, and coal we keep extracting from the Earth. But carbon-removal advocates say we desperately need to do both things at once: cut future emissions and reverse the impacts of

With cooling towers each large enough to hold London's Big Ben tower inside, the United Kingdom's mammoth Drax Power Station is transitioning from burning coal to relying on biomass wood pellets. Eventually, says its parent company, the Yorkshire facility will...Read More

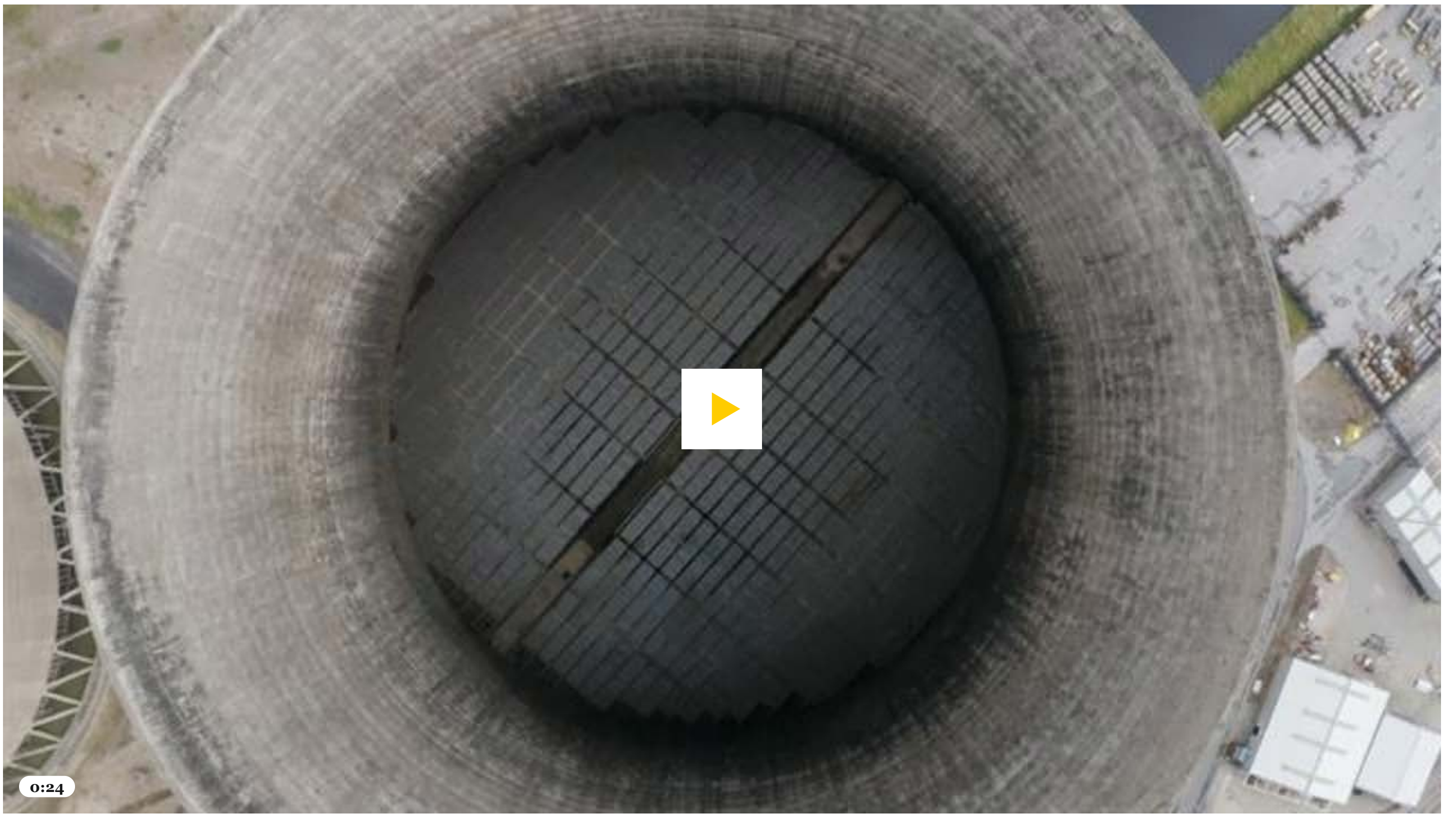


"It's very clear to me that this is *a* solution to the problem, even if it's not *the* solution," Aradóttir says. "Basically, we are going to have to do this on top of everything else the world must do to decarbonize all the energy we use."

Or, as Matthew Warnken, chair of an Australian company, Corporate Carbon, put it to me: "People ask me all the time, 'Wow, is this a silver bullet for the problem of climate change?' And I say no, it's not. But it is silver buckshot—and we're going to need it."

Warnken's assertion stems from projections by the United Nations Intergovernmental Panel on Climate Change (IPCC) that any realistic pathway to dealing with the climate emergency must include carbon removal on a vast scale. To keep global temperature from increasing above a critical threshold of 1.5 degrees Celsius (2.7 degrees Fahrenheit) over preindustrial levels will require achieving carbon neutrality *and* removing as much as 12 billion metric tons of $CO_2$ annually by mid-century.

That is a staggering challenge: We add three times that much in greenhouse gas emissions in a single year.




Drone footage captures the eerie scene inside one of the Drax Power Station's enormous cooling towers.

An employee at the U.K.'s Drax power plant holds wood pellets, now the principal source of the facility's biomass-to-energy production. A shovel once used to load coal—the plant's previous energy source—looms in the background.

Iceland's birch forests had been reduced to one percent of the nation's land area by the middle of the 20th century. Now, because trees store carbon, the Icelandic Forest Service is encouraging their growth. The most recent tree census found that woodlands like t…Read More



**Nearly all $CO_2$ now sequestered** comes from nature and conventional nature-based solutions like planting trees and changing farming practices to improve soil's carbon retention. For now, whiz-bang technology like the "direct air capture" plant that traps the carbon dioxide Carbfix shoots underground in Iceland counts for just 0.1 percent of $CO_2$ removal.

Planting and tilling will not be enough to address this crisis, says the IPCC, especially since they could take up land and water needed to grow food. Yet the technology of carbon removal remains inordinately expensive and been around for a while. Like cold fusion or green hydrogen, it is a moon shot that has never really gotten off the launchpad.

But now the industry has begun attracting serious money, which those involved say will propel the research and development needed to bring down the cost of direct air capture and other forms of carbon removal. Climeworks, the Swiss company that runs the $CO_2$-trapping plant in Iceland in conjunction with Carbfix, secured $650 million from investment firms earlier this year, the largest such private investment the burgeoning industry has seen so far. The company's corporate customers—including Microsoft, JPMorgan Chase, and the payment systems firm Stripe—are eager to purchase verified "offsets" that enable them to claim they're operating their businesses on a carbon-neutral or even carbon-negative basis.

Climeworks' co-founder, Jan Wurzbacher, says direct-air-capture technology will plummet in price, just as the cost of solar panels and wind turbines has dropped in recent years. Built in modular units, each the size of a standard shipping container, his company's devices can be widely transported by ship, rail, or truck and fit together as neatly as Lego blocks at their final destination.

Climeworks' direct-air-capture plant in Iceland—the largest such facility in the world—removes 4,000 metric tons of CO2 from the atmosphere each year. That's equivalent to annual emissions

"This is very doable, from a practical point of view, to get to a point where you are really helping to address the problem," explains Wurzbacher, a German-born mechanical engineer who came to Switzerland as a college student and stayed put.

"There is no reason you could not build hundreds of thousands, millions, of these units. Now, is there a moral hazard? Maybe. But what can we do about that? Maybe 20 years ago it was an either-or proposition. But now it's a both-and. It's an all-hands situation."

Wurzbacher's goals for how much carbon his company will remove by direct air capture are bold. One megaton annually, or a million metric tons, by 2030; 100 megatons by 2040; by 2050, one gigaton—a billion metric tons—a year. At today's prices, Climeworks' annual revenue would be more than double that of Apple. But Wurzbacher says the comparison is not apt, because he expects the costs per metric ton of cleaning the air to drop precipitously.



Climeworks' Iceland facility, the world's first commercial carbon dioxide–removal plant, uses a system of giant fans and filters to trap the $CO_2$, all powered by geothermal heat, a fact that serves to highlight one of the technology's limitations, at least in its current state. Direct-air-capture projects must run on clean renewable power—otherwise they would wind up emitting almost as much carbon as they remove from the atmosphere.

An offshore rig called the *Transocean Enabler* drills injection wells more than a mile below the North Sea, creating a network of subsea reservoirs able to absorb 1.5 million metric tons of $CO_2$ annually, equivalent to the emissions of about 320,000 cars.



With a mop of brown hair and a restless air giving him an early-Beatles vibe that belies his 40 years, Wurzbacher personifies the youthful optimism common to many carbon-removal start-ups. Perhaps a bit of the impishness, as well. Speaking in London a few years ago, Wurzbacher threw several 10-pound trash bags on the stage to illustrate a point. Dumping his trash wherever he wanted would be the easiest and cheapest way to deal with it, he told the crowd, but society long ago decided it would

Greenhouse gases should be no different, he concluded, except that humanity has generally allowed these emissions to go untaxed, unmitigated, and unpunished.

Now, there is a value to removing carbon dioxide from the atmosphere: Like any other product in the market, it's what individual consumers and corporations are willing to pay. And some polluters are willing to spend big. Anytime you hear of a major airline pledging to become "carbon-neutral" by 2030 or 2040, it's certainly not expecting that its jet engines will magically stop emitting $CO_2$ by that date. Instead, it's planning to buy carbon offsets from companies like Climeworks and Carbfix.

But as important as that money is for spurring R & D, it's a minute fraction of what would ultimately be needed to make a genuine difference in reversing or at least slowing climate change. That figure would likely be measured in the trillions of dollars, amounting to one of the largest industrial undertakings in all of history. In the words of the science fiction author-philosopher Kim Stanley Robinson, reclaiming our carbon emissions from the air around us will amount to nothing less than a "civilizational project."

Pound for pound, kelp and other seaweeds hold more CO2 than trees. Camila Jaber, a Mexican free diver, explores the immense kelp forest off Argentina's Tierra del Fuego during a 2022 expedition to determine whether Patagonia's underwater macroalgal forests can b... Read More

PHOTOGRAPH BY MARIA LAURA BABAHEKIAN

**Deep in the outback of Australia,** 12 hours north of Adelaide along a road that turns into a red ocher dirt track as it wends into one of the least densely populated areas of the world, lies an enormous natural gas field known as Moomba. By the time the road reaches its terminus, at the edge of the gas field, general services run out: Moomba doesn't welcome outsiders without permission.

What Moomba and the rest of the massive outback do offer, Julian Turecek assures me with expansive enthusiasm, is perfect conditions for operating tens of thousands of solar-powered modules that can trap carbon dioxide and lock it away in the crevices under the dusty earth.

"Sun, space, and storage!" explains Turecek. "Australia has all of those in abundance."

Backed with contracts ultimately funded by Stripe and the parent companies of Facebook and Google, Turecek's enterprise is developing the modules in a Brisbane laboratory and plans to begin installing them next year at Moomba. The business, Aspira DAC, is a unit of Corporate Carbon, an Australian firm that sells credits for certified carbon removal from the atmosphere.

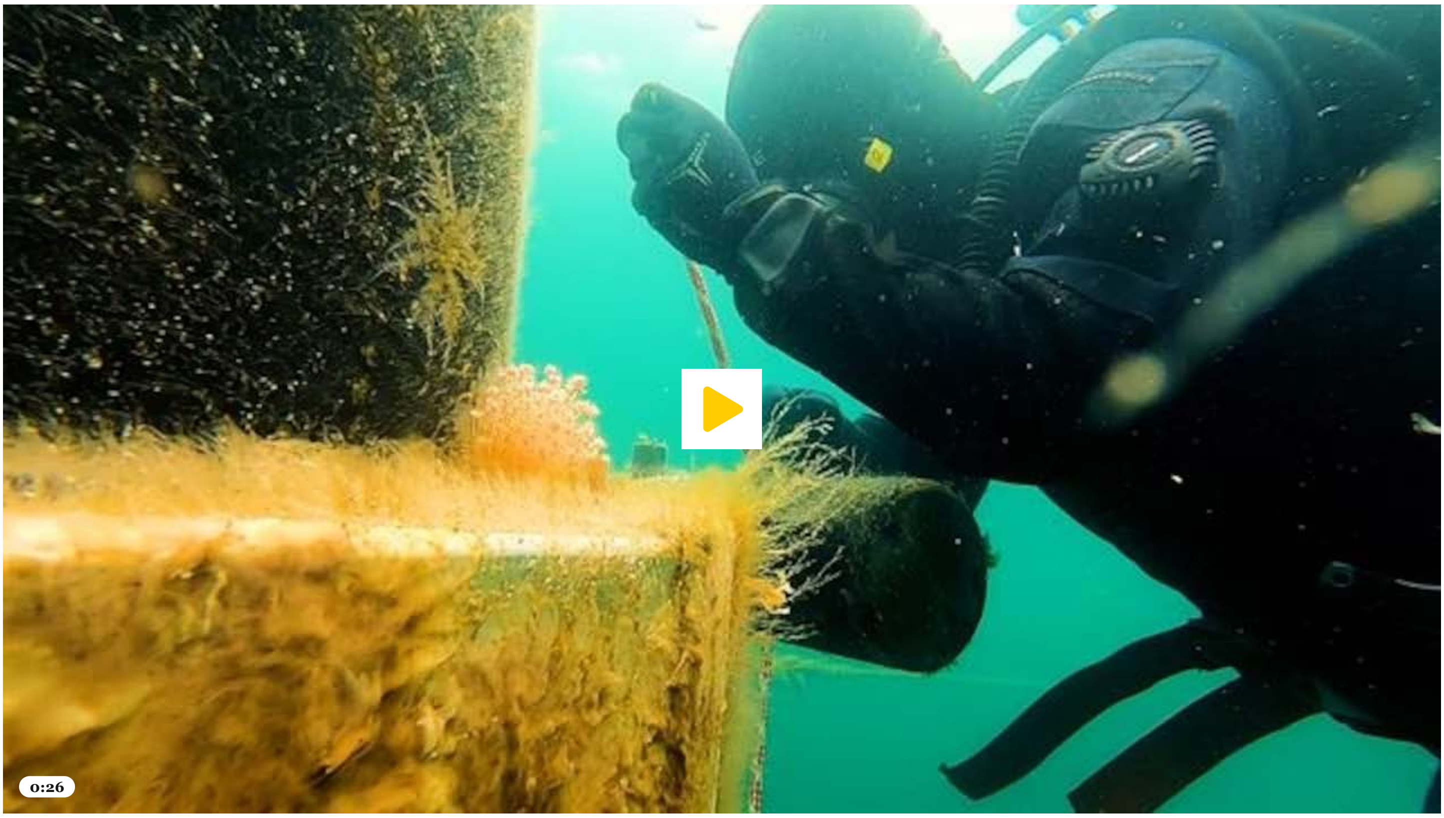
Each unit is roughly the shape and size of a two-person tent, with two solar panels measuring six and a half feet in either direction forming the sides. The panels power a fan that blows air across a polymer honeycomb-like device that filters $CO_2$, cycling through a 20-minute period of absorbing the gas, followed by a 10-minute de-absorption process that releases the $CO_2$ into a collection system. The units are equipped with enough battery power to run through the night, as long as there's been adequate sunshine to power the batteries. In the broiling outback, that's generally not a problem, Turecek says.

"We think there will ultimately be hundreds of thousands of these, in different remote parts of Australia," says Rohan Gillespie, managing director of Southern Green Gas, a renewable energy start-up that's building the units in conjunction with Aspira DAC. "There could be a million or two." Each module can capture a total of two metric tons of $CO_2$. (A metric ton, also known as a tonne, is about 2,200 pounds, or 10 percent more than a standard U.S. ton.)

Interestingly, one thing carbon removal clearly has going for it is that it can be done anywhere on Earth: Carbon dioxide is just as usefully sequestered in the outback as it would be in, say, car-dependent Los Angeles. That's because the gas disperses so quickly and thoroughly in the atmosphere that its concentrations are generally uniform across the globe.

Australia is something of a pioneer in research into carbon removal, with ample government support, although not entirely for altruistic reasons. Conservative prime minister Scott Morrison, who led the country from 2018 to 2022, pledged to make Australia a world leader in the technology, which he said would help it achieve “net-zero” status by 2050. But the nation is also the world’s biggest exporter of coal, and Morrison expressed no interest in decreasing its role in supplying China, India, and other parts of the developing world with as much of the energy source as they wanted. Nor did Australia move on from coal as its chief source of domestic electricity.

In that sense, Morrison’s policy illustrated precisely the moral hazard environmentalists warn against: relying on carbon removal as a way to avoid or delay the transition to clean energy from dirtier, carbon-rich sources like coal, oil, and gas. The more moderate government that replaced Morrison’s last year is equally enthusiastic about carbon capture although also somewhat more bullish on green energy jobs replacing those in the coal industry.




A diver performs underwater maintenance on a mesocosm in Norway, where scientists are testing how effectively alkaline materials sequester carbon dioxide in the ocean.

**Direct air capture** remains the flashiest of carbon-removal approaches, the biggest technological fix and the one its boosters say has the greatest potential to scale up to the enormous needs envisioned by the IPCC. Its intellectual godfather is a man named Klaus Lackner, a genial but intense physicist who runs the Center for Negative Carbon Emissions at Arizona State University.

When I visit him at his lab in Tempe, he's experimenting with the latest version of what he calls "mechanical trees": three-story-tall, carbon-sucking, -filtering, and -storing devices. He says they're about a thousand times more efficient than actual trees in sequestering $CO_2$. And they're better at keeping carbon dioxide locked away. After all, a real tree eventually releases all its $CO_2$ when it dies.

"I believe we can solve this problem at an affordable price!" proclaims Lackner, who has been working on his idea since before the turn of the century. The reason the idea hasn't really caught on yet, he argues, is that the industry suffers from a classic chicken-or-egg dilemma. It needs generous infusions of cash to fund all the research required to bring the technology up to the scale that will drive its per-tonne cost sharply downward. But it's hard to attract such funds when the price remains so high.

That could be changing, however. The Biden administration's huge Inflation Reduction Act, signed into law in 2022, includes development money and potentially billions of dollars in tax breaks for companies that develop or adopt direct-air-capture technology. Recently $1.2 billion was awarded to two direct-air-capture plants in southern Texas and Louisiana. (The terms "carbon removal" and "carbon capture" by now are used interchangeably in common parlance but technically have different origins and meanings. Carbon capture involves removing $CO_2$ at a concentrated emissions source, such as a factory smokestack; carbon removal refers to any technology that removes carbon dioxide from the atmosphere.)

> If we can synthesize kerosene for fuel from the air around us and make it carbon-neutral, then we have the solution to a lot of our problems. Just think of it!
>
> **ALDO STEINFELD**, ENGINEER

Lackner also points to construction already under way in West Texas by Carbon Engineering, a Canadian consortium recently purchased by Occidental Petroleum, which is building a direct-air-capture plant that dwarfs the Iceland facility. Intriguingly, the new operation, intended to remove up to one million tonnes of $CO_2$ annually—the equivalent of taking about 217,000 cars off the road—is being built in the Permian Basin. Thus, one of the iconic locations for the launch of the oil industry could become similarly known for putting massive amounts of fossil fuel–derived carbon

As an evangelist for direct air capture, Lackner says the key question is not whether the technology works, but what price society will be willing to pay for it.

“At $600 a tonne, people say, ‘Oh well, it’s just not practical,’ ” he explains. “At $100, they would probably go, ‘Hmmm … that’s expensive, but you know, maybe it’s worth it.’ At $50, it’d be, ‘Wow, this starts to look good.’ At $10 a tonne, it would be a no-brainer.”

Lackner calculates that several thousand carbon-removal plants, situated around the globe on land whose total acreage would roughly match the size of Arizona, would be enough to bring global $CO_2$ back down to levels that would prevent climate change from causing catastrophic damage. When I ask him whether he thinks this will happen, he offers a pithy response, variations of which I hear from other capture enthusiasts around the world.

“I’m a technology optimist,” Lackner tells me, “but I’m a policy pessimist.”

The policy to which he refers—or the lack of one, really—is the failure of governments around the world to make people pay for their carbon emissions, in the form of a tax or tradable emission permits. He uses the same trash analogy I heard in Zürich from Wurzbacher, with Climeworks. “We can and should do precisely that same thing for carbon,” says Lackner, “because we know just how damaging it is for the planet. But we’ve failed to do it. So like I say, I don’t think this is really a technology problem so much as it is a problem—or a failure—of the collective will.”

Cement production accounts for 7 percent of global CO2 emissions. Until a cost-effective way to sequester CO2 in cement is found, the Heidelberg Materials plant in Brevik, Norway, plans to use alternative fuels and a carbon-capture system to cut emissions in half starting in 2024.


Deep underground, a machine mines raw materials for the massive Heidelberg Materials plant, which produces 1.2 million metric tons of cement a year. Its program to capture CO2 is part of the Norwegian government's Longship project to reduce carbon dioxide's impact a… Read More

**If you happened to be standing** at North Sea Beach Colony along Long Island's Little Peconic Bay in New York one morning in July 2022, you would have encountered an unusual sight. A bevy of construction vehicles unloaded and graded some 500 cubic yards—about three dozen dump trucks' worth—of mint-colored sand, mixing it with the existing sand while a team of scientists took careful measurements. It looked a bit like someone adding several dashes of green food coloring to the beige beach tableau.

All this green sand wasn't being imported to the Southampton beach for whimsy, aesthetics, or a test run for a future St. Patrick's Day surprise. Instead, it was the beginning of a pilot project aimed at bringing carbon removal to the two-thirds of the planet covered by ocean.

The operation amounts to a giant speedup of natural weathering processes, explains Kelly Erhart, the co-founder and president of Vesta, a San hopes to spur a commercial industry that one day could remove carbon from the oceans for as little as $35 a tonne.

“We’re talking about Earth’s long-term cycles and whether it’s possible to expedite them in order to reverse the harm of climate change,” says Erhart. “We want to use something that normally takes millions of years and make it happen within a span of decades. So there’s an urgency to it.”

The green sand in Long Island is actually finely ground olivine, a type of magnesium iron silicate that is common in Earth’s upper mantle. In the presence of water, the olivine absorbs $CO_2$ in a natural chemical process yielding bicarbonates that sequester carbon. The amount of carbon dioxide absorbed increases as the available surface area of the olivine increases, which is why Vesta uses a special kind of olivine ground down to microscopic crystals.

Like Vesta, an entire branch of carbon-removal research is looking to the oceans, rather than air or land, for large-scale results. Proponents of this approach say that all the talk about planting trees to absorb $CO_2$ is obscuring a forest of possibility underwater: seaweed, which pound for pound can be as much as 40 times more efficient than trees in sequestering carbon.

> “
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> We want to use something that normally takes millions of years and make it happen within a span of decades.
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> **KELLY ERHART**, CO-FOUNDER AND PRESIDENT, VESTA

“If we use the natural infrastructure of the ocean and create large seaweed islands, we could see a dramatic decrease in the main driver of climate change,” Pia Winberg, a marine systems ecologist, says as she gives me a tour of an old paper mill on the coast of New South Wales, Australia, that she has repurposed as a sort of mecca for all things seaweed.

PhycoHealth, the company Winberg founded in part to draw attention to seaweed’s potential for fighting climate change, offers an impressive menu of products made with seaweed and algae. It sells seaweed kombucha, seaweed fettuccine, and seaweed granola, as well as supplements, probiotics, cosmetics, and skin-care products that are all derived from seaweed extracts.

Seaweed stews and bubbles in large steel vats as Winberg explains to me existing one as a highly regarded marine researcher.

“Seaweed could be cleaning up the world, but so far most people just aren’t aware of this,” she says with a rueful smile. “At some point I realized I needed to stop just writing papers about it but start selling a product that people want. Put it in the food that we all eat every day, and then you can educate people about the miraculous power of seaweed to heal the planet.”

Winberg and others advocate for government involvement because, they say, it’s too difficult for individual companies to raise the capital needed to start such an industry from scratch, and, as with the olivine solution, research is needed to demonstrate both its effectiveness and its safety.

Proponents say giant offshore “kelp farms” could rapidly absorb $CO_2$ and easily sequester it for the decades necessary to get the climate into a safer state with a lowered concentration of carbon dioxide. The surface area of the ocean required would be large, but not significant when measured as a percentage of the ocean’s total. Still, even the advocates caution that much more research needs to be done to verify the consequences—intended or otherwise—of such a widespread tinkering with nature.

Entrepreneurs are scrambling to transform CO2 into products people will buy, including diamonds. Aether creates the gems from captured atmospheric carbon dioxide rather than the usual energy-intensive mining.


**Left**: With a process that mimics photosynthesis, Air Company has devised a range of luxury

**Right**: "What do you do with captured CO2? The answer is that you can turn it right back into the useful products that used to be made from fossil fuels," says Nicholas Flanders, co-founder and CEO of Twelve, a company that makes aviation fuel out of carbon dioxide and water.

At Post Carbon Lab in London, Dian-Jen Lin and Hannes Hulstaert design clothes that photosynthesize using microbial dyes (like those growing in the dish) to remove CO2 from the atmosphere and release oxygen. "Fashion has traditionally been based on an exploi... Read More

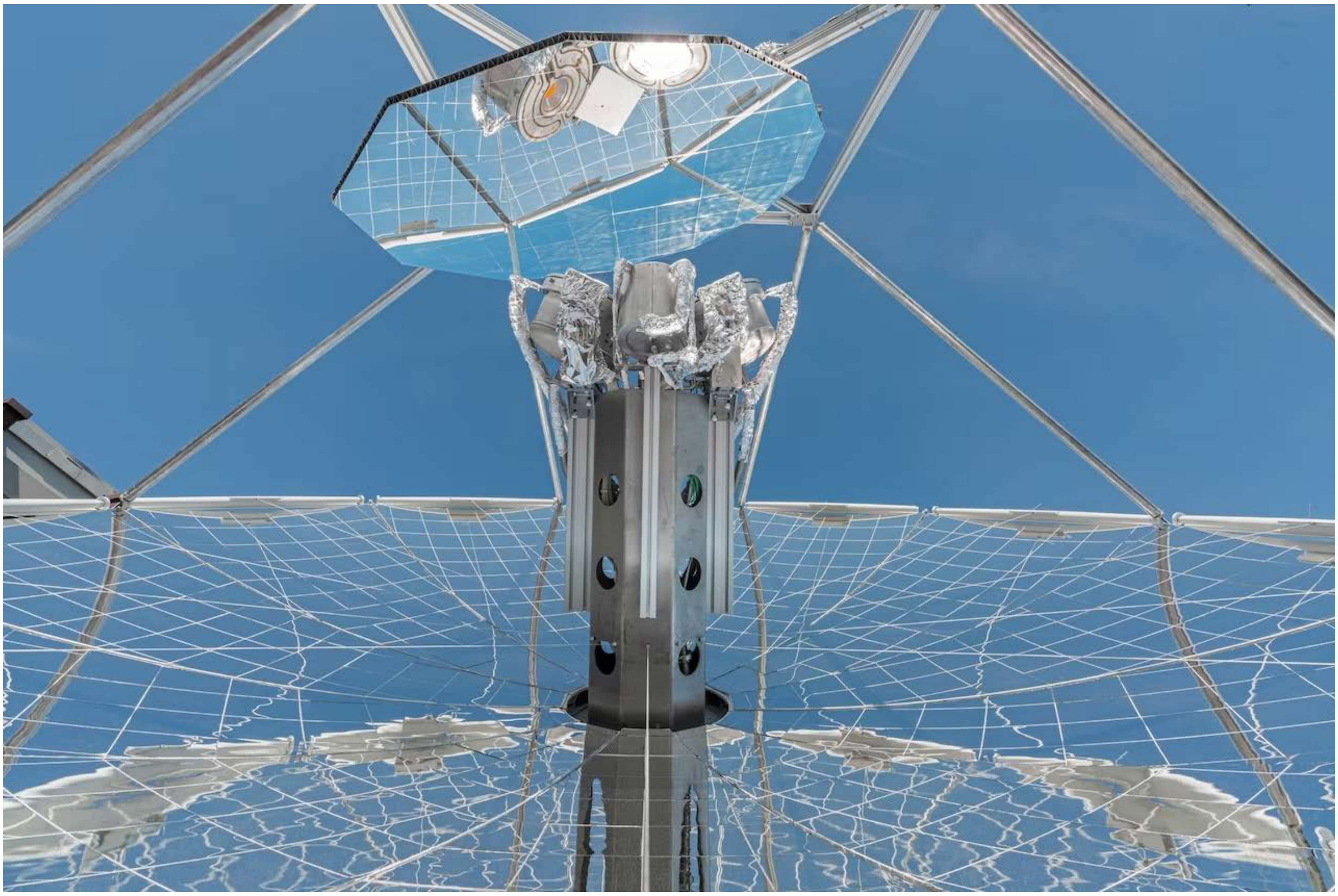
**As a boy growing up in Montevideo,** Uruguay, Aldo Steinfeld developed a passionate interest in chemistry, which nearly turned lethal one day when he mixed up a compound of colorful chemicals and ignited his grandmother's apartment.

Everyone survived, but today, almost exactly 50 years later, Steinfeld is still playing with fire. Now he does so atop a science building on the campus of ETH Zürich, a university often referred to as Europe's answer to MIT. Steinfeld specializes in sustainable energy systems. Among such systems, the one for which he has an abiding passion is the holy grail of carbon capture and reuse: creating hydrocarbon fuels from nothing but sunlight and the air around us.

Using a dodecagonal-shaped collection of mirrored panels about the size of a large beach umbrella, Steinfeld shows me how sunlight can be focused into a beam so intense that it's capable of splitting $CO_2$ and water into component parts in two separate streams: carbon monoxide and hydrogen in one stream, which forms the basis for what he calls "solar synfuel"—solar-synthesized fuel—and oxygen, which is vented back into the atmosphere.

"The circular economy of it is the beautiful thing," Steinfeld tells me, proffering a small vial of the liquid, a sustainable alternative to fossil-derived transportation fuels such as kerosene, gasoline, or diesel. "Carbon doesn't get added to the atmosphere—it's getting collected and reused. If we can synthesize kerosene for fuel from the air around us and make it carbon-neutral, then we have the solution to a lot of our problems. Just think of it!"

The intriguing concept has yet to take off commercially because it demands a lot of expensive solar panels to create a tiny amount of fuel. Here again, the problem is chicken-or-egg. Steinfeld says building huge solar arrays in strategically located areas equivalent to about one-half of one percent of the entire area of the Sahara desert could bring down prices radically and provide carbon-neutral synthetic kerosene for the entire global aviation fleet. It's certainly a grand vision, but so far—aside from a commitment by two airlines and the Zürich airport to use the fuel on a trial basis—no one has signed on to invest in the gargantuan infrastructure needed to bring it to reality.



Atop an ETH Zürich university building, a small solar power refinery captures CO2 and water to produce what researchers hope will become carbon-neutral jet fuel—if the high cost of the process can be brought down through refinements and mass production.

Still, Steinfeld's idea of a virtuous cycle of carbon consumption and reuse took us so long to figure out the path to energy utopia. For now, though, mired in our early 21st-century modes of inquiry, carbon removal (let alone carbon recycling) remains a supremely hard nut to crack. It might never have been needed at all had we put a realistic price on carbon's impact a few decades ago, when it first became clear that anthropogenic generation of $CO_2$ was warming the planet. Instead, we're at a point where removing carbon is absurdly expensive, potentially counterproductive (see "moral hazard"), and absolutely necessary.

Carbon itself is hardly our foe. It will remain, of course, essential to life itself—the basic unit for organic molecules. Some 18.5 percent of the human body mass is carbon, more than any other element except oxygen. Plants need carbon from $CO_2$ for photosynthesis, and while you may hardly think of it anytime you are cc'd on an email, the acronym stands for "carbon copy," a throwback to the days when extra copies of a paper document could only be made by pressing a typewriter's keys onto the original as well as a carbon-film solution underneath it.

But there is simply too much carbon in the atmosphere around us—a genie we once brilliantly popped out of the bottle but one we now are struggling to rein in. It will require all the ingenuity we can muster.

"We can do this," says Klaus Lackner, the self-professed technology optimist. "We can provide the energy the world needs, and we can clean up after ourselves."

I hope he's right. Toward the end of my time in Iceland, my wife, Lisa, joined me for a bit of sightseeing. We headed out of Reykjavík to navigate the so-called Golden Circle, a route full of waterfalls, glaciers, geysers, and other geological marvels that highlight Iceland's wild and spectacular beauty. Even though I'd already been to the spot several times for interviews and other reporting, I pulled off the main highway and down a dirt road near the mammoth Hellisheiði geothermal energy complex.


conceded. To the unknowing eye, it wasn't much more than a few cargo containers stacked together with some large fans whirring around inside. At present, the machinery there can snare a paltry 4,000 tonnes of carbon dioxide from the air in a year, all of about three seconds of our annual global emissions, or hardly an eyeblink's worth.

Nonetheless, I pointed out, this plant may yet come to be seen as we see Henry Ford's Model T factory or the Wright brothers at Kitty Hawk. This could be the place where something really big began, the place where we finally started cooling the Earth by putting all that carbon back where we found it.

**Sam Howe Verhovek** is a frequent contributor to *National Geographic*. He wrote about aviation's struggle to go green for the October 2021 issue.

Originally from Italy, **Davide Monteleone** is a visual artist and researcher who focuses on themes of geopolitics, data, and science. He's been an Explorer since 2019, contributed to publications including *Time* and the *New Yorker*, and had work exhibited in London, Paris, and Rome. For this issue, he had to figure out how to make images about an invisible gas. "My work is an opportunity to learn something new and extraordinary," he says.

This story appears in the November 2023 issue of *National Geographic*.

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