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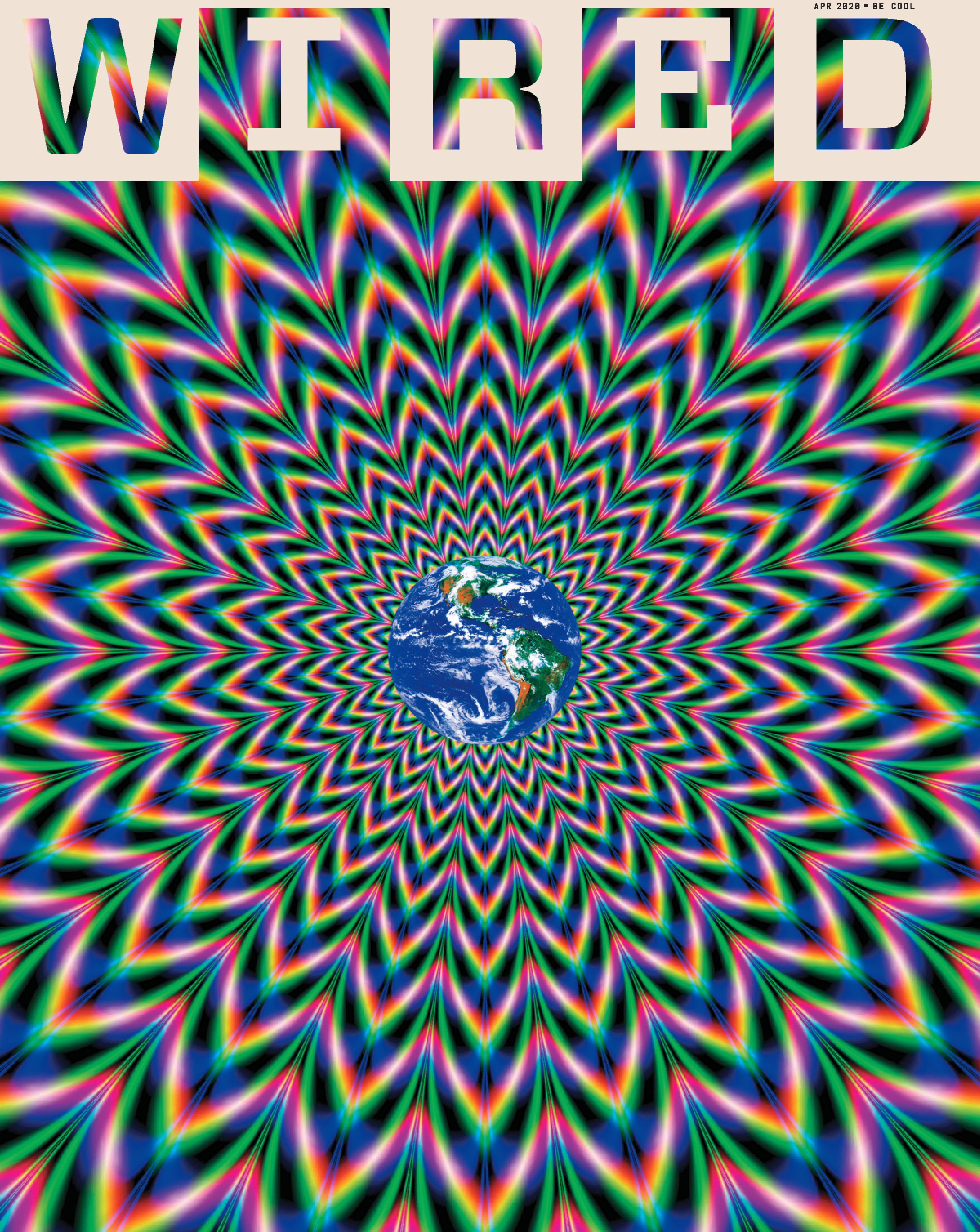

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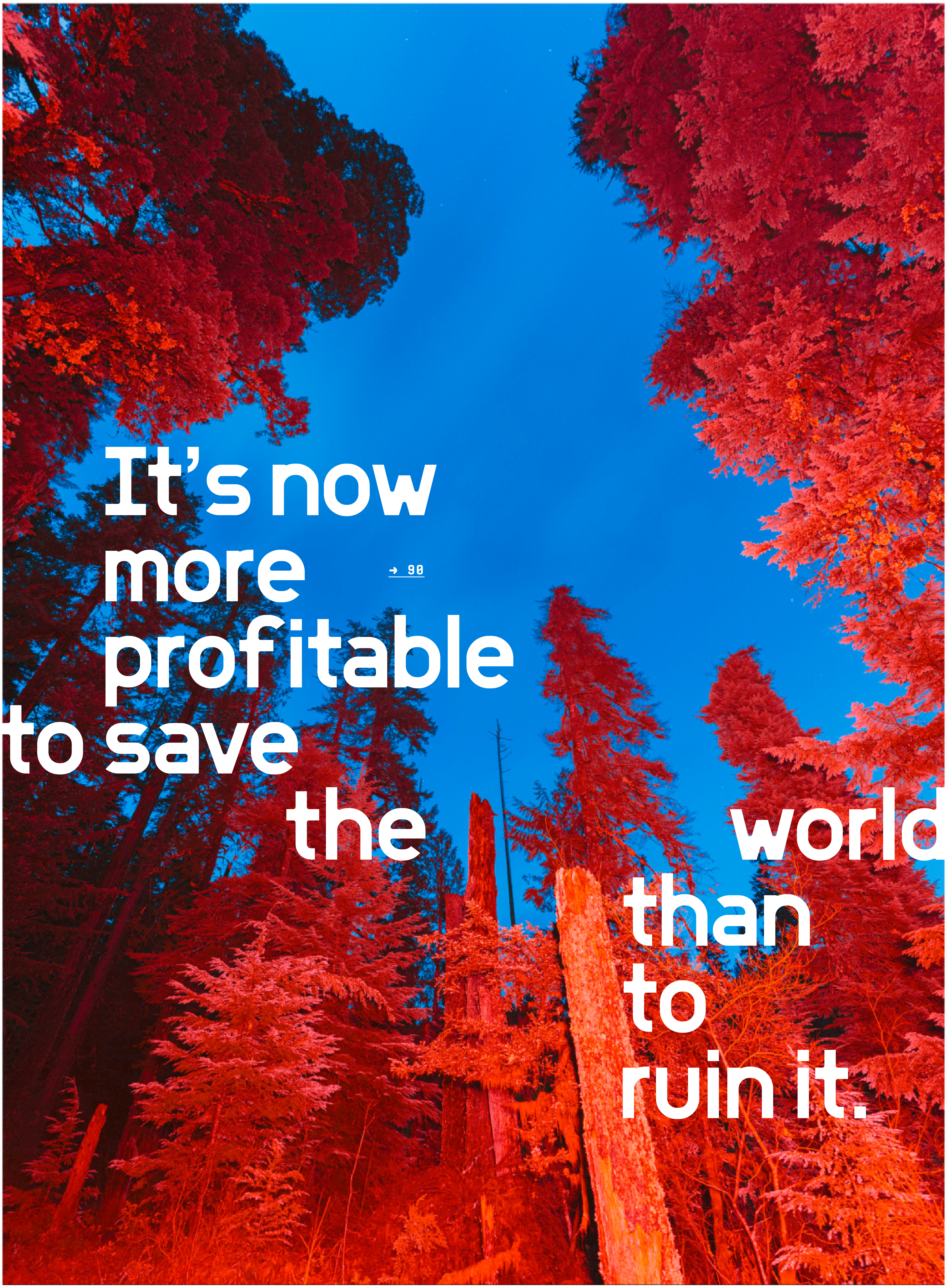

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The Climate Issue

WE HAVE THE TECHNOLOGY. HERE'S HOW WE CAN MAKE THE BIGGEST IMPACT—ASAP!

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Earth on cover: NASA

“The Cold War institutions of Darpa and Arpa-E, the DOD, national labs, and even new sources of green capital are more shovel-ready than the mind of the American voter.” page 12

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Start

THE ONLY
OPTION IS
TO ACT NOW

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An Awesome Question

_How can we make the biggest impact on climate in the next 10 years? Go!

NOT LONG AGO, I WAS DRIVING WITH MY three sons back from trying to ski on a mountain that doesn't really have snow anymore, and we were talking about climate change. They're 11, 9, and 6, and they're upset, as they should be. They know that their adult years will be spent in a world of raging fires, flash floods, and mass extinction. They love Greta and resent their elders. The future feels different and vaster when the actuarial tables give you 80 years to go, not 40.

We talked about turning our thermostats down, eating less meat, and putting the cable box on a smart plug. I promised to install solar panels. I tried futilely to explain what capitalism is and why it was still a reasonable way to organize human affairs, despite CO_2 levels now reaching 415 ppm. I told them there was still time. They found my explications unpersuasive and mostly shared each other's anger (except when the older boys reported that some environmentalists argue against having three children; that didn't go over well with their little brother). Gradually, though, their rage turned to pragmatism. That's when my oldest son asked: "If there's one thing that I could invent that would help, what would it be?"

It's an awesome question—maybe a quintessentially 11-year-old one. From our first moments of consciousness up through childhood, the things we think we might be able to do with our lives broaden and broaden. And then, at some point around adolescence, they start to narrow. Our imaginations shrink, our obligations grow, we charge ahead on certain roads and avoid the ones less traveled. Eleven is wonderful. You're aware of the world and its limitations, but if you're lucky your imagination hasn't been crimped yet. Really, maybe, you can do anything.

The question hung for a second, and then I just took my best guess. "Maybe build a better battery?" A breakthrough in energy storage could go a long way toward improving the prospects for electric cars, the wind industry, and the entire renewable economy, I said. Maybe there's a way to store much more electricity in a smaller space, without requiring cobalt from the exploitative deep mines of the Congo.

In retrospect, it's not a terrible answer. But I wasn't sure if it was the best one. I thought a lot about the question after we arrived back home. And then, at a meeting here at WIRED, I floated it by my colleagues. In due course, either because it's a great question or because parents overestimate their children—and journalists overestimate their bosses—it became the inspiration for this entire issue.

Yes, we did end up taking some liberties with the question, stretching it in some ways and constraining it in others. We primarily focused on technology that exists today, so there are probably fewer wizarding-world-type projects than my children would like. And we narrowed the scope of our assignments to what we consider the five most crucial areas: how we eat, how we move around, how we keep the lights on, how we capture carbon, and how we can set up institutions that can take the risks needed to solve this problem. Children who are now in booster seats, all around the world, are going to be inventing solutions to the crisis, and they'll need support, investment, and, yes, well-designed capitalism to get them off the ground.

Even we optimists at WIRED know this is a very, very bad situation—likely the most complex problem humans have ever faced. We know that a lot of what has been lost is never coming back, and to grieve is human. But WIRED's purview is the future, and really the only way to think creatively about the future is with something like optimism. Not the blind kind, but the informed kind. We can be hopeful without being obtuse.

We want our readers to feel empowered when they finish reading, because the solutions are gathering steam all around us. We can lay carbon-sucking concrete in cities that have largely exiled cars. We can reengineer rice paddies and then store our leftover rice in vastly more efficient refrigerators. We can even, yes, make better batteries. We can solve this.

BY Nicholas Thompson

ILLUSTRATION BY Eiko Ojala

NICHOLAS THOMPSON *(@nxthompson) is* WIRED'S *editor in chief.*

The Warm War

_How to mobilize the same federal machinery that gave us Wi-Fi, semiconductors, GPS, and the internet—this time to fight climate change.

BY Lisa Margonelli

THE FIRST HUGE RENEWABLE-ENERGY revolution—the one that dotted the US with hydroelectric dams and ultimately made power ubiquitous in every American home—started at a bankruptcy sale. In 1877, Jacob Schoellkopf went to an auction for a waterway owned by the Niagara Falls Canal Company. A succession of entrepreneurs had tried and failed to harness the ferocious power of the falling water. That night he told his wife, "Momma, I bought the ditch."

Two years later, Thomas Edison made a light bulb that glowed for 40 continuous hours in his lab. Three years after that, Schoellkopf installed a generator below the falls to power 16 electric lamps above it.

Those first lights wowed tourists and gave people a sense of the powerful waterfall's potential. But they didn't reveal how to generate power that could travel long distances, never mind how to make a profit on it. For the next 14 years investors tried to harness the falls (one engineer proposed building a long tunnel beneath them to feed 38 vertical shafts with turbines that could power factories above), but everyone failed. It took Nikola Tesla's invention of an efficient polyphase generator to transmit those electrons—and the sale of his patents to Westinghouse—to make hydro viable. In 1896 the "Cathedral of Power" started sending watts to the towns of Niagara and Buffalo, right next door.

But this 17-year sprint from the lab to Buffalo was, in a sense, only a proof of concept, what we might now call a demonstration project. It would be another quarter century before even a third of US homes got electricity. In 1905 there was a political backlash against the idea of diverting the public beauty of the falls for the gain of private companies. "Shall We Make a Coal-Pile of Niagara?" asked the *Ladies' Home Journal*, sparking one of the first examples of federal legislation focused on the environment. The politics of power began to shift, as people realized how important it was; in 1912 a federal report noted that 60 percent of hydropower in the US was controlled by just two companies. In 1931, New York governor Franklin Delano Roosevelt created a state power authority that could act as a check on private monopolies, announcing that he was giving "back to the people the waterpower which is theirs." It would take FDR's national power initiatives to eventually wire all of rural America. Today Niagara Falls creates enough electricity to power 3.8 million homes, and hydro plants provide 16 percent of the world's electricity.

Niagara's long timeline is worth remembering as we get serious about reducing carbon emissions fast enough to keep average global temperature increases below 2 degrees by 2100. To accomplish this we will need to push many techno-Niagaras from the light-bulb-in-the-lab stage to full deployment around the world—within just a few decades. These days we tend to think of such energy revolutions—with all of their attendant bankruptcies and political backlashes—as impossible tasks. Or only for dreamers. But this is not true. In fact the United States has led such sweeping technological revolutions before, and we could do it again. But we'll need to dismantle some old myths and ideologies about who bankrolls innovation and who benefits.

Americans are, in general, complacent about innovation, assuming the solution to our energy problems is one brilliant new mind away. A few more Elon Musks and we'll be saved. But it's been obvious for nearly a decade that the private sector isn't getting us where we need to go. In 2011 there were 1,256 patents filed for global-warming-related energy technologies; by 2018, only 285 were filed. And US venture capitalists, long seen as the drivers of global innovation, have been eschewing the cleantech sector since their investments peaked at over $7.5 billion in 2011. They invested less than $2.4 billion in 2019. Today's VCs, with their focus on quick profitability, would see the transformative powers of Niagara Falls as nothing more than a bankrupt ditch.

Nor can we rely on the traditional high-carbon energy companies that sell oil, gas, and electricity to lead us into a clean energy transition because, in addition to bankrolling opposition to climate change, they are heavily vested in an infrastructure and business model that stands to be overturned by new technology.

It's increasingly clear, then, that the kind of fast, transformative technology development and adoption we need will require the government to take the lead.

RIGHT ABOUT NOW, PEOPLE USUALLY START to mouth the phrase *moon shot*—in homage to the taxpayer-funded innovation binge that started in 1961 and ended in 1972, organized around the discrete goal of putting a man on the moon and bringing him safely home. Whenever Americans pine for new ways to solve problems, that's the go-to nomenclature: Google X wanted a moon shot; the NIH has a cancer moon shot; environmentalists and labor created an "Apollo Alliance" in 2003. Little wonder that the moon shot is so attractive in hindsight: It had a single, clearly stated goal; it united Americans during a decade of upheaval; it resulted in one giantly successful step; and it spun off other advances. But in a way, the cult of the moon shot actually understates what government can do. A decade, the lesson seems to be, is about as long as the American public can stand to bankroll its geeks and wizardesses to make gizmos.

To get to net-zero emissions, though, we need not one decade but many. And the task of truly reducing emissions while coping with a changing planet is vastly murkier than depositing a human on a rock. First we need to mightily improve the nascent technologies underlying electric vehicles, energy efficiency, and advanced renewable energy storage—and get them into general use. At the same time, we have to foster technology that is in earlier stages (like carbon capture, fuel cells, and sustainable biofuels) out of labs and into large-scale demonstration projects where they can be tested and tinkered with until they can be scaled up. Finally, we need to explore and develop tech that's barely visible on the horizon, like new types of nuclear reactors and methods of capturing carbon directly from the air. And as we go along, each technology will bring its own challenges, while new crises arise, literally, from the atmosphere. We have to be ready for that.

We're talking about at least 30 years of taxpayer-led investment in innovation, probably more. This is no moon shot; this is an entire cold war. In fact, the Cold War itself is a very useful and instructive precedent for anyone who wants to bring the full might of the US government to bear on a warming planet. "The planners who started to contend with the Cold War didn't know what it was and how long it would take, and yet they committed resources to dealing with it," says Daniel Sarewitz of the Consortium for Science, Policy & Outcomes at Arizona State University. "It's similar to the emergent issue of the climate—where we'll ultimately manage it with many technologies rather than solving it with a single one."

An era of government-led technological innovation, modeled after the loose bipartisan consensus over the strategy of containment that guided us in the Cold War, would be equal to the task of cooling the planet. Not only that, but the complex federal machinery that delivered some of the greatest innovations of the mid-20th century is still lying around, waiting to be fired up and duly aimed.

IMMEDIATELY AFTER WORLD WAR II ended, funding for military technology fell dramatically. Nuclear weapon and jet engine development slowed, while US troops in South Korea, outfitted with obsolete weapons, suffered defeats that inspired the military to get directly involved in research. Vannevar Bush, who had been the director of the wartime Office of Scientific Research and Development, argued in a 1945 report titled "Science—The Endless Frontier" that American peace and prosperity required significant government investment in innovation. Bush advocated heavy spending on curiosity-driven science in university labs as well as funding for federal laboratories like those that had been part of the Manhattan Project. Under the existential threat of nuclear war, US leaders embraced Bush's vision of science, combined with military development of technology, as a path forward in an uncertain time.

The Cold War inspired the creation of several key publicly funded organizations, many of them military, that have reconfigured the nation's economy, and the world's, through a series of transformative technology booms. The Defense Advanced Research Projects Agency (Darpa), which was founded by President Eisenhower in 1958 as a response to Sputnik, has been credited with laying the groundwork for the internet, Wi-Fi, supercomputing, desktop computing, GPS, robotics, artificial intelligence, drones, and voice recognition. Through the '50s and '60s, the Department of Defense learned how to best use its position as a primary customer to spur industries to create better and more innovative technologies—a process that has brought to market three of the most important energy technologies of the past century: nuclear power, sophisticated and efficient turbines, and solar photovoltaic tech. (The depth of the military's influence on the US economy is so profound that, to understand its role, I found myself reading an economics book titled *Is War Necessary for Economic Growth*? The answer was, with some qualifications, yes.)

As Arati Prabhakar, who led Darpa from 2012 to 2017, explained to me, "We are very good at innovating in this country for the things that we set out to innovate for in 1945: national security, which led to changes in information technology, and health, which became biomedicine. And I don't think it's an accident that that's what we're good at now—because those were precisely the things that we focused on."

The military has been successful at creating tech for a few reasons: As Prabhakar suggested, it sets priorities for problems it wishes to solve and then pursues multiple technological pathways. What's more, it perseveres without caring excessively about costs.

Take Darpa itself. According to MIT's Bill Bonvillian, who has studied the agency's role in innovation for more than two decades, Darpa's greatest advantage is its uniquely nimble, collaborative, mission-driven culture, where managers move back and forth between research and application, creating communities among researchers and industry. "In most R&D agencies, the critical decision is awarding the grant," he says. "In Darpa, the managers award the grants and then move into the researcher's home."

In addition to providing what economists call the "technology push" by funding foundational science through Darpa, the military also excels at creating a "demand pull" by partnering with industry to develop the products, mounting large-scale demonstration projects, and being an early-adopting customer with deep pockets. Many of these innovations have made their way into civilian life.

Every time you board a 737, for example, you are experiencing the result of the Army's demand pull in the world economy. In the early '60s, Army and NASA engineers set out on a program of basic and applied research to radically change the way they understood jet engines, in a bid to make them much more energy-efficient. As researcher John Alic has documented, they went deep into the physics of the machines, studying the way air flowed over the blades and how metals behave at high temperatures. They funded basic research on rare earth magnets at university labs and developed ceramic coatings that are now standard for high-temperature uses. With the Army spending billions of dollars on research and then purchasing expensive products that spun out of it—like Apache helicopter blades—not only did jet engines become more efficient and reliable, the private sector adopted and built off of the new technologies to create civilian products—like that passenger aircraft, the turbines in gas-fired power plants, and even the magnets that run the electric windows in your car.

The US has wallowed in the politics of climate despair since the late 1990s, so it may be hard to accept what I'm going to say next: We could fairly quickly adapt our existing federal technology innovation system to work on the tech we need to decarbonize energy at a scale that would have real impact. (What's more, by shifting innovation from military applications to civilian ones, we'd be building a country where war is no longer necessary for economic growth. But that's a different conversation.)

As it happens, we've already successfully cloned Darpa to create a civilian entity that works exclusively on energy and the climate. In 2009, Congress budgeted $400 million to the Advanced Research Projects Agency-Energy (Arpa-E) at the Department of Energy. It even staffed it with former employees of Darpa. Though it has a small budget (these days, one-tenth of Darpa's), Arpa-E is widely considered a success. By 2018, the agency had funded 660 early-stage energy innovation projects, including innovative batteries that could be used to back up renewable energy on the grid, floating offshore wind technology, and new systems for maintaining advanced nuclear reactors.

It would not be hard to combine Arpa-E's early-stage development work with the Department of Defense's knack for scaling technology into practical uses. Dorothy Robyn, a former deputy undersecretary of defense who is now a senior fellow at Boston University's Institute for Sustainable Energy, argues that we should significantly increase funding to Arpa-E and then have it work with Darpa and the Department of Defense to mount large-scale projects to develop things like microgrids, advanced solar photovoltaic cells, and energy storage facilities at military bases and other properties. "It's low-hanging fruit," she told me.

So how could this happen? First, the president or Congress would need to define carbon as an existential threat and make decarbonization a general mission. Then, task the military and the national labs—and many other government agencies—with committing resources to the rapid development and deployment of technology to accomplish the mission together.

Of course, getting government entities involved in bringing technology to market will require them to change the way they approach their work. Consider another venerable Cold War asset, the country's network of 17 national labs, which are part of the DOE. While several of the national labs have programs that match scientists with money, mentors, and expertise to form startups, in general the labs now focus on basic research and try to stay above the fray of commerce. As Prabhakar observes, "If you wanted to make a caricature of it, you'd say people [at the labs] are afraid to actually have an impact. Over time the mission of a lot of public funding and basic research has been just to focus on publication, citations—which are important but don't suffice to meet societal needs."

Another candidate in need of change is American industry; though Cold War behemoths like IBM, McDonnell Douglas, and General Dynamics once developed everything from semiconductors to jet engines, profiting from the process, they are no longer on the forefront of innovation. According to Ilan Gur—former Arpa-E program manager and the current head of nonprofit Activate, which offers fellowships at federally funded labs to cleantech scientists to start businesses—"Today's industry is not incentivized by Wall Street to do all the speculative work to develop those technologies themselves." Gur supports dramatically increasing funding to Arpa-E, but he—and others—also point out that we'll need to entice big manufacturers to jump in as well. "The force multipliers come from engaging industry—you're not going to win a lot of these games by just sprinkling budget dust in at the early stages."

> Getting the political system to buy into the reality of climate change is still the struggle that transfixes the people who write and worry about the environment. Meanwhile the climate itself has moved on, and soon the discussion will too.

AS POWERFUL AS GOVERNMENT CAPITAL CAN BE in a time of international urgency, there are also two relatively new sources of "budget dust" that could help carry risky but necessary technology over the ditch and into the market.

The first is really a reinvention of another Cold War idea: venture capital. The original VC company, American Research and Development Corporation, was formed in 1946 to invest in "noble" technology created by the war effort. When that fund invested $200,000 in a firm that made machines to deliver radiation to cancerous tumors, one of the VC founders, MIT president Karl Compton, observed that they didn't expect the company to make money, but the "ethics of the thing and the human qualities of treating cancer" made up for that. Then, almost accidentally, the company—High Voltage Engineering Company—turned out to be worth $1.8 million when it went public in 1955. The VC made even more money when another investment, Digital Equipment Corporation,


CapitalOne
Savings Rate
5X
National Average

went public in 1966. Soon what had been "noble" capital started to become moneymaking capital; tax laws were changed, pension funds jumped in, and venture funds became a giant profit-seeking asset class that proudly compared itself to a shark.

There is now a broad movement afoot to return the venture capital model to its philanthropic roots, specifically where climate change is concerned.

Bill Gates' Breakthrough Energy Ventures and, more recently, Jeff Bezos' Earth Fund are both multibillion-dollar philanthropic entities that act, essentially, like very risk-tolerant angel investors. There are others, too, including Arati Prabhakar's Actuate, which plans to use philanthropic funds to do interdisciplinary research with a social payoff. The Cambridge, Massachusetts–based Prime Impact Fund, which draws from multiple sources of philanthropic wealth, issues long-term loans to startups that promise to launch "gigaton-scale emissions projects" like extracting lithium sustainably, pulling carbon dioxide from the atmosphere, and heating and cooling in environmentally friendly ways. If a single investment yields returns, those can be reinvested or contributed to another philanthropic cause. If investments don't work out (they are high-risk, so of course some go bust), the contribution will be viewed much the same as a traditional grant.

If the idea of giving billionaires tax breaks while they decide which climate technologies get angel funding makes you nervous, there is a more democratic option—green banks, which use public capital as seed money to make low-interest loans to companies with emissions-reducing technology. Green banks have some bipartisan support, and a recent House proposal suggested endowing a nonprofit national climate bank with $35 billion in federal funds. Reed Hundt, founder of the Green Capital Coalition, says that such a public investment would be leveraged to borrow $350 billion, which could then be loaned to projects that have the potential to reduce carbon emissions significantly. By reinvesting this money as the loans are paid off, he says, the scheme could put $1 trillion into early-stage technology over the next 30 years.

Green banks could be coupled with other public initiatives like government-backed green bonds, or even something like war bonds, which would allow individual investors to put their retirement money to work supporting an environment they wouldn't mind growing old in. Hundt sees green capital expansively: "The goal here is to have renewables provide cheap and clean power to 100 percent of humanity really, really quickly, while at the same time shoving the carbon industry into the past."

THIS SOUNDS WONDERFUL, DOESN'T IT? WE already have the tools, we have the people and the programs, we even have a decent amount of capital. So why aren't we already making the future happen faster and shoving carbon into the past?

It's ironic, but in many ways all these Cold War institutions and the relatively exotic new sources of philanthropic and green capital are more shovel-ready than the mind of the American voter. What's wrong with us? The answer, I think, is that we have been conditioned to be passive about technological growth, and after years of arguing over whether climate change is occurring, we've also become resigned to the idea that tackling it in a robust way is politically impossible. It is time for us to reexamine these myths—and also to design a new innovation system that benefits more people more directly.

Blame a legacy of Cold War secrecy, as well as a much more recent dogma that relentlessly celebrates individual entrepreneurs. The economist Mariana Mazzucato, director of the Institute for Innovation and Public Purpose at University College London, has spent years studying the way the US government uses taxpayer funding for innovation. She points out that the system has long socialized the risks of bringing technology to market while privatizing the gains when entrepreneurs such as Steve Jobs applied that technology to consumer goods. In other words, a lot of innovative tech that has made some people rich was built on public investment, but taxpayers have no idea they underwrote the whole thing.

Mazzucato suggests that taxpayer-funded innovation should instead put us in control—by including ways for citizens to influence policy, transparency in funding, and ways for the funders—us—to profit. And politicians should start talking about taxpayer investments in technology as a source of pride. "You're part of this massive shift in global capitalism, greening production, distribution, consumption patterns—it kind of makes you happy to be alive!"

But what about the politics? For the past 25 years, the challenge has been getting the political system to simply buy into the reality of climate change. Because that was a long and exhausting war to which many people dedicated their careers, it's still the struggle that transfixes the people who write and worry about the environment. Meanwhile the climate itself has moved on, and soon the discussion will too. It's already happening: Republicans have begun proposing carbon taxes on the floor of Congress. As the future unfolds with one Australian fire or Indonesian flood after another, magnified by social media, investing in climate technology will become a point of bipartisan agreement.

Anyway, as Niagara Falls showed, technology changes politics almost faster than it changes the world. Building a better, cheaper solar panel could accommodate any number of ideological positions, from support for a Green New Deal, a wonk's preference for cap and trade, a Republican carbon tax, a more libertarian turn toward local microgrids. Or, for that matter, a 21st-century FDR could reincarnate and entirely nationalize the electrical grid. We should anticipate these shifts by deploying technology in ways that give more power to the very people who have funded its development.

When we do begin to decarbonize our world, there will be new challenges: We'll need to get used to the very weirdness and randomness of faster innovation—the notion that what starts with light bulbs over a waterfall winds up sparking an environmental movement and handheld computers filled with cat memes. This is what Activate's Ilan Gur calls "the stochastic nature of innovation"—the sheer unpredictability of what happens when a technology hits the complex system that includes markets, global societies, and the planet's climate. "But the one thing we know is that if you don't define the horizon of change that you want to see, and you don't plant those seeds of innovation, then you won't ever get there."

LISA MARGONELLI *(@LisaMargonelli) is the author of, most recently,* Underbug: An Obsessive Tale of Termites and Technology.

Here's Where You Come In

_You can't solve the climate crisis alone. And we also can't solve it without you.

BY Mary Annaïse Heglar

ILLUSTRATION BY Alvaro Dominguez

ONE AFTERNOON IN DECEMBER, I TOOK THE 4 train from my home in the South Bronx to an apartment near Union Square. I had been invited to lead a conversation with a handful of artists about the climate crisis and their place in it.

What I found was an intimate gathering of six or seven people. After some milling about over plates of cake and mugs of coffee, we started remembering Hurricane Sandy. We marveled at how much our experiences differed based on the borough or neighborhood we lived in. Sandy turned the Lower East Side—which was originally built for low-income communities but is now fairly affluent—into a place where police cars were submerged and electricity was scarce. Meanwhile, the South Bronx, originally built for the affluent but now the poorest congressional district in the country, came out of the storm relatively unscathed, since it sits on higher ground and is connected to the mainland of New York state.

We wondered how long before another Sandy—or something much, much worse, perhaps something we don't even have language for yet—pushed the masses from Lower Manhattan into the South Bronx. Then where would my neighbors go?

From there, the conversation naturally spiraled into the undercurrent of terror that comes with being alive today. Australia was ablaze, and the embers had barely cooled in the Amazon. A typhoon was encroaching

Getty Images

on the Philippines. And that wasn't counting the countless other disasters underway in Africa and Latin America that never made the headlines. Even on our way in, we couldn't help but notice that it hardly seemed like December outside.

I could tell that it felt good to talk like this: open and honest about the experience of watching the world fall apart in front of our eyes. To say our fears out loud and have them, and ourselves, accepted and understood.

It was almost like I could see the weight lifting from our shoulders. But as that weight lifted, it only rose so far. It hung in the air, just above our heads like a heavy ominous cloud, until someone finally popped the question that brought the weight back down on us:

"But what can we, as individuals, do?"

SOMETHING REMARKABLE HAS HAPPENED TO the climate conversation in the past two years. It's finally found its way out of the academy, oozed out of the Big Green groups and expert circles, and landed in the streets and on everyone's lips. I hear it everywhere: on the street, in the subway, in the airport, in the changing room at my yoga studio, in the checkout line at the grocery store. It's not niche anymore. It's mainstream.

It's beautiful.

For me, it's also bewildering. I am what the meteorologist and journalist Eric Holthaus calls a "Climate Person"—someone whose whole life is bound up in confronting the reality of the climate crisis. I joined the environmental movement in earnest in 2014, when I began working for one of the biggest green groups in the country. About a year ago, I also began speaking out on my own—in essays, on panels, and in Twitter rants. This made me not just a Climate Person but a Public Climate Person.

We Climate People are used to being a small group. Marked by our intimacy with one another, our knowing glances across rooms. We're used to being mocked and sidelined as the killjoys, the bummers. In public places, we intuitively gravitate toward one another, carving out our own little corner of the party or our own sliver of the internet known as #ClimateTwitter, where we can rant and rave and scream and grieve together.

But our cover has been blown now, and the doors of our clubhouse have been torn off the hinges by hordes and hordes of brand-new Climate People. If I had to guess what did it, I'd say it was the 2018 report from the Intergovernmental Panel on Climate Change, which spelled out in brutal and unequivocal—but most importantly, *honest*—terms the consequences of a runaway addiction to fossil fuels.

Finally, the general public got a glimpse of what we Climate People stare in the face every day. Once you see it, as we well know, you can't unsee it. And when the shock finally passes and you find your feet again, you're overcome with the urge to do something—anything—to wash as much blood off your hands as possible.

Suddenly, Climate People are popular! Where we used to quietly lament our lack of dinner party invitations and hold our own parties in secret, we're now the belles of the ball. Before, people rolled their eyes, smacked their teeth, and backed away when I mentioned my work. Now they lean in close. They ask questions and actually listen to my full, uninterrupted answer—men included!

And no question is more fervent, more persistent, more desperate than the one that weighed us all down in December: "But what can I do?"

There's probably no question that Climate People hear more, and fear more, than those five words. The askers get more and more frustrated, their newfound sense of urgency threatening to burn a hole in their throats.

They know it's about more than recycling, "buying green," and turning the lights off when they leave the room. They've gotten the memo that we need structural change in addition to individual change. They've processed past the shock. They're ready to get to work. Why, they demand to know, can't I give a simple answer to such a simple question?

Here's why: Because if you want a real answer—one that won't leave you with tiny solutions that will ultimately disempower you and burn you out—you have to understand that the question is profoundly complicated.

BELIEVE ME, I UNDERSTAND WHY THAT QUEStion seems so cut-and-dried. But that's just an illusion conjured by several fallacies. And perhaps the first thing a new Climate Person can do is understand them.

Let's start with the first fallacy: that climate action is an individual thing. Almost every time I hear people struggle to find their place in the climate movement, it's because they feel unable to do enough to make a difference. They know that the world needs to essentially bring fossil fuel production to a screeching halt, not just now but RIGHT NOW. And they know that no one action they take can bring that about. So then what?

Well, what if your power in this fight lies not in what you can do as an individual but in your ability to be part of a collective? What if you broadened your perspective beyond what you can accomplish alone and let yourself see what you could do if you lent your efforts to something bigger? Yes, it's true that you can't solve the climate crisis alone, but it's even more true that we can't solve it without you. It's a team sport.

Another fallacy: the expectation that a single, neat behavior change will be enough. I've done a lot of interviews, sat on a lot of panels, and I've often heard the question "What can I do?" boiled into an even more maddeningly and damningly simplistic form: "What's the *one thing* people can do?" There's no such thing. I wish there were.

Especially now, at this critical stage, we have to accept we're all going to have to buckle down for the long haul. Responding to this crisis is going to have to become part of who we are. All the time. Once you understand that, you understand that this isn't about climate action at all. It's about climate commitment. Climate action is recycling or going vegan. Climate commitment is bigger. It's a framework. It's asking yourself: What can I do next? And always next.

Then there's that other alluring fallacy: the idea that if we do the right thing, we can put an end to this madness. That there's a stop button somewhere.

As the climate scientist and brilliant writer Kate Marvel puts it, "Climate change isn't a cliff we fall off, but a slope we slide down." The climate has already changed, and so what's been done, sadly, cannot be undone, at least not in the near future. But there's real good to be done by not letting it get worse. Limiting the damage is good, noble—valorous even.

By now, you're probably becoming either consciously or subconsciously aware of the heartbreaking truth at the core of the climate crisis: It's so unfair. It is. That's probably the simplest thing about climate change—the injustice. It's apparent at the macro and micro scales. The parts of the world that contributed the least to the crisis will suffer first and worst. Mere children have been thrust into positions in which they have no choice but to fight for their lives, for their right to see the stable planet they were taught about in storybooks and science books but have never seen in real life.

No, it's not fair.

But now that you're aware of that truth, it's crucial to remember one thing: It's not enough to be right. The facts have been on our side for a very long time, but we're still losing. Why? Because this isn't a spelling bee or a standardized test. This is a fight for justice.

The climate crisis is, in more ways than I can count, the ultimate culmination of a centuries-long run of exploitation and extraction, including slavery and colonialism and all of their offshoots. Those horrors were all justified by some measure of pseudoscience that could have been—and was—easily disproved. But that wasn't enough. So it is with the climate crisis.

The scientists and experts have studied the problem and the solutions and presented their findings ad nauseum. But it wasn't enough. Because this isn't just about science or facts. This is about power. And it's going to take an army. That's where you come in, new Climate Person.

I KNOW IT MIGHT NOT SOUND LIKE IT, BUT there's a lot of good news in there. For one thing, you don't have to do this all alone. In fact, you can't. Because we're talking climate commitment and not a single climate action, that means you don't have to worry about nailing it. This is a practice, which does away with the need for perfection. The fact that every fraction of a degree of warming—Celsius or Fahrenheit—matters means that you're never too late or too small to help.

The right time to start your climate commitment is always right now.

But the question remains. "What can I do?" Well, now that you understand that the question is complicated, the answer actually emerges as quite simple: Do what you're good at. And do your best.

If you're good at making noise, make all the noise you can. Go to climate strikes, call your representatives, organize your neighbors. Vote. Every chance you get. Join something bigger than yourself because this is so much bigger than any of us alone. It's about all of us, together.

If you're raising children (and they do not have to be your children—nieces, nephews, and play cousins all count!), teach them to love the earth and to love each other, teach them the resilience that shows up as empathy. If you're good at taking care of people, take care of the legions of weary climate warriors. If you're a good cook, cook. Make it as sustainable as you can within your means, but more than anything, share it, build a community around it.

The artists I spoke to in December lamented the fact that they weren't engineers or scientists or some other type of "expert." But as I told them, it is not their job to design the policy plans for rapid decarbonization, to decide which coal plants to shut down first, and what exactly to replace them with. We have people on that. As the writer Toni Cade Bambara once put it, the role of the artist is to "make revolution irresistible."

Severing ties with fossil fuels is nothing short of a revolution, a rebirth. The truth is our world was built on fossil fuels. It never should have happened, but it did. There's no reversing it. That's why we need a whole new world, and we all, every single one of us, has a powerful role to play as a midwife in this rebirth.

Taken through that lens, you begin to see that you're not powerless at all. Far from it. The world is not falling apart in front of our eyes so much as it is falling into our hands. What will happen if we're brave enough to catch the falling pieces?

That's why it's so impossible for any Climate Person to tell any other Climate Person, new or old, what their own climate commitment should look like. We don't know that special thing that you bring to the movement—only you know that. And we can't wait to see the magic that will happen now that you're part of our world.

Do what you're good at. And do your best. If you're good at making noise, make all the noise you can.

MARY ANNAÏSE HEGLAR *(@MaryHeglar) writes about the intersections of climate, justice, and emotion.*

Christie Hemm Klok

"There are scientists racing to invent technologies that pull carbon from the air, but here, all around him, were billions of needles and leaves that already did it, day in and day out." page 24

Capture

HOW WE'LL CUT THE CARBON

Force of Nature by Brooke Jarvis — p. 24

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Emission Control by Matt Simon — p. 35

→37% THE PART THAT "NATURAL CLIMATE SOLUTIONS" COULD PLAY BETWEEN NOW AND 2030 TO KEEP GLOBAL TEMPERATURE RISE BELOW 2 DEGREES C.

Force Of Nature

Plants are already socking away a lot of carbon for us. They could soak up a lot more—if we help.

BY Brooke Jarvis

PHOTOGRAPHS BY Cody Cobb

KEN BIBLE STEPS OVER A CARPET OF bracken and vanilla leaf to get closer to the big Douglas fir. He gives its furrowed bark an affectionate slap, as if introducing a prize racehorse.

"It's about 70 meters tall and 2.6 meters in diameter," Bible says, leaning back to take in the behemoth stretching above him. From way down here on the shady floor of the forest, he has no hope of seeing all the way to the tree's top. But thanks to a 279-foot-high tower that rises above the trees, Bible, who helps manage this site on behalf of the US Forest Service, has had the chance to know this old Doug from above as well as below.

From hundreds of feet up, at canopy level, he says, you begin to get a new vision of the complexity of structure that defines an old forest. "It looks like a mountain range," Bible says. "You've got ridges and peaks and valleys." Singular trees like the big Doug reach high over their neighbors. At around 500 years of age, it isn't the oldest tree in the forest, but a lucky location near a wetland has made it one of the biggest.

The Doug is lucky in other ways too. Once upon a time, its particular seed happened to fall from a particular drying cone into what, hundreds of years later, would become a small section of protected old growth inside the Wind River Experimental Forest, a research area in southern Washington state originally created to study the best ways to exploit forests for human use. Just outside the confines of this 1,180-acre remnant of old forest, the trees of the Doug's generation are long gone. Some were killed by fire, others by pests, and others were removed by foresters who, for more than a century, had been using the area as a testing ground in their attempt to find the best ways to turn the great forests of the Northwest into profit.

It was here at Wind River, on the slopes of an ancient volcano above the Columbia River, that Northwestern forest researchers began in the early 1900s to engineer the protocols that would govern the industrial-scale removal of the region's trees. It was here, in large experimental plots, that they compared the merits of different timber species and tree genetics, of novel methods for replanting and spacing; here that their experiments convinced them that Douglas firs would be the cash crop of a new industry and that the industry's methods should favor large clear-cuts and burns; here, too, that more than 800 million seedlings were reared to replace all the forests that would be systematically logged across millions of acres of the Northwest over the coming decades. Those seedlings served to solve a problem the industry would know not as "deforestation" but as "inventory depletion." According to the new protocols, the transplanted seedlings would be grown and harvested in plantations where every tree was the same age.

Bible's big Douglas fir, and the old-growth acres around it, survived only because one of those early researchers, a Yale Forest School graduate named Thornton Taft Munger, insisted on establishing a control for their experiments. The purpose of research at Wind River was to improve on the efficiency of nature by replacing forests with human-engineered tree plantations, he argued—so of course the experimenters needed to maintain a bit of nature against which they could compare their success. (The idea of the reserve nevertheless seemed odd to at least one Forest Service director, who responded with incredulity that anyone would bother to protect something as mundane and inexhaustible as old growth. "We've got 20 million acres of virgin timber in the National Forests," he wrote. "Why set up this special area?") In the end, Munger got his permission and set about measuring tree growth within the protected forest as well as outside of it.

It was a visionary act, but even Munger—for whom the reserve is named—saw no inherent value in its quiet, needle-dusted acres of firs and hemlocks and cedars and alder, beyond their use in research. According to the orthodoxy of the day, old trees were worthless and wasteful: effete, slow-growing, and decaying relics that ought to be ripped out and replaced with young and vigorous plantations. "There is little satisfaction in working with a decadent old forest that is past redemption," Munger told a conference of loggers in 1924. (He had a particular hatred for standing dead trees, known as snags, which are a common feature in mature forests. He once wrote an entire essay about snags, in which he argued that they deserve "outlawry": "They stand, fringing the skyline like the teeth of a broken comb, in mute defiance of wind and decay, the dregs of the former forest, useless to civilization and a menace to life.") This general contempt for old growth defined the field of forestry for decades. "We grew up thinking of old forests as biological deserts or cellulose cemeteries," says Jerry Franklin, a forest ecologist now renowned as the father of a very different school of thought. "We climbed over huge piles of downed logs and woody debris, and we didn't think about anything other than how to get rid of it, how to liquidate it."

By late in the 20th century, the timber industry and its methods were well established and, according to the historians Margaret Herring and Sarah Greene, Wind River "began to become almost a backwater of forest research, a museum of old experiments." A large tract of Munger's old-growth section was nearly clear-cut in the 1960s—foresters agreed that its utility for research was exhausted, and it was still understood to have no other value—and the area was again threatened in the 1980s, when Congress decided it would be a good spot to test whether a military surplus balloon, lifted by four helicopters, could be used for logging in remote areas. (The project was abandoned when the contraption crashed during a test flight in New Jersey.) The Doug stayed lucky, and the forest stayed intact.

_ Livestock accounts for roughly 14.5 percent of anthropogenic emissions worldwide. However, if farmers fill their pastures with trees and shrubs—an ancient technique known as silvopasture—their grazing land will absorb up to 10 times more carbon.

It wasn't long before researchers were glad it had endured. Where once foresters had worked to study how to most efficiently remove wood from a landscape, a new generation of scientists began to study the efficiency with which a forest, by creating wood, could remove carbon from the air. They realized that, after so many years of focus on their young, experimental plots, they did not yet fully understand the intricate workings of a mature Northwestern forest.

Wind River's old-growth area now hosts the National Ecological Observatory Network (NEON), which gathers data at 81 field sites across the United States and makes it available to anyone interested in tracking how global change is affecting specific ecosystems. On a bright but bitter November morning, I hike with Bible and some NEON employees to the tower that overlooks the forest. (The tower was once part of a construction crane used to hoist gondolas full of scientists up to study the Wind River canopy, but the crane's boom was decommissioned in 2011.) Researchers now use the tower to measure, in exquisite detail, the carbon cycle within Wind River's old growth. Along its length, the tower is outfitted with eight levels of sensors and cameras, a cavity ring-down spectrometer, and something called a sun photometer, part of a gadget accurately described to me as looking like a robotic arm that's going to "shoot down UFOs," which uses detailed measurements of radiation to determine the nature and quantity of aerosols in the atmosphere. Inside a hut at the bottom of the tower sits a stack of servers to back up the reams of ecological data that are constantly zipping off by satellite to NEON headquarters in Colorado. From there, it's now possible to watch the way carbon dioxide flows differently at the forest floor and the canopy, or to see it temporarily build up in windless groves after trees have stopped photosynthesizing for the night.

We like to imagine that climate change will eventually be solved via grand mobilizations of futuristic technology, and this is surely an impressive one. But as Matt Schroeder, NEON's assistant director of field science, tries to help me understand the maze of wires and machinery, he confesses himself to be more impressed by the engineering wizardry that surrounds the tower. There are scientists racing to invent new technologies that pull carbon from the air, but here, all around him, are billions of needles and leaves that already do it, day in and day out. Through the profound, irreplaceable, utterly ordinary bit of magic that is photosynthesis, trees build themselves from almost nothing, transforming sunlight, carbon dioxide, and water into millions of tons of biomass—approximately half of which is pure carbon, locked safely away from the atmosphere. And old trees, by virtue of their age and size, can hold far more carbon than anybody else.

"Our technology has to be protected in this box," says Schroeder, gesturing at the hut where the tower's cables and servers and gas cylinders are kept. "Whereas *this* technology"—he stares up at the towering, once-denigrated old trees and all the hundreds of tons of carbon locked away in their massive trunks—"just *works*, year-round. It runs on solar power. It creates all of this from thin air."

Schroeder shakes his head, looking freshly wonderstruck and not like he'd been studying the trees for years. "We have no technology that could do this. The DNA on this landscape has done this."

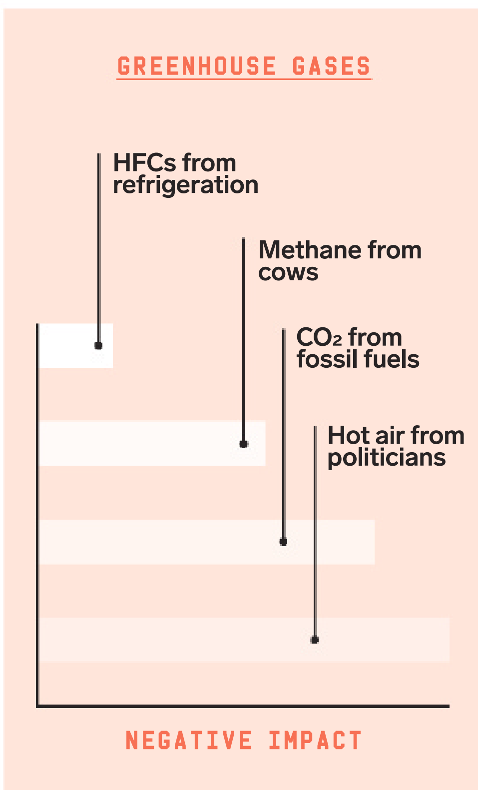
THE CLIMATE SCIENTIST KATE MARVEL called the 2010s "the decade we knew we were right"—the decade when long-predicted calamities associated with a changing climate began to manifest clearly in our own real world, coming true "with a terrifying rapidity that is no more reassuring because it is easily understood." From the melting of the Arctic or the bleaching of the Great Barrier Reef to fires and floods and hurricanes and droughts and buckling permafrost, this decade has been both heartbreaking and ominous. We are beginning to experience, faster than any of us hoped we might, how much we have depended on a stable climate, how much we stand to lose now that we are destroying it.

Yet for all the terrifying speed with which the consequences of climate change are now making themselves known, it's important to remember that things could be much worse.

Last year, humans dumped roughly 40 billion tons of carbon dioxide equivalents into the atmosphere, despite knowing that those emissions will create even more warming and planetary havoc. It was a fresh test of our commitment to our survival and well-being, and once again we failed, quite abysmally. Luckily for us, though, this is a test that, simply because of where we live, is always graded on a curve. Only something like half of those 2019 emissions will stay in the atmosphere and continue to make our predicament worse. The rest are obligingly absorbed by forests, like the one at Wind River, as well

Chartgeist

BY Jon J. Eilenberg



_Excess brush and timber in forests can be removed to prevent wildfires and then slow-baked in a low-oxygen environment to create charcoal-like biochar. When buried, biochar can nourish parched agricultural soil, promote food production, increase water efficiency, and hold carbon in the ground for centuries.

as by the world's grasslands, wetlands, soils, and oceans. These natural sinks, as they're known, remove carbon from the atmosphere and lock it away, protecting us, if only in part, when we fail to protect ourselves.

More than a decade ago, while working as an intern for the National Park Service at a small park in Hawaii, I got an eye-opening lesson in just how generous nature's curve can be. Given the assignment to calculate the park's contribution to climate change, I spent weeks dutifully pulling records about electricity use in park buildings and gasoline burned in park trucks, about how much methane we'd generated with our trash and how many hydrofluorocarbons with our refrigeration; I tried to calculate the fuel burned to allow employees to fly to conferences and the barge that delivered our supplies from Honolulu to make its annual trip to our remote location. But when I entered all that information into a program that would calculate our total carbon footprint, I was shocked: It estimated that, *poof!*, the carbon sequestration provided by the park's forest cover—the scrubby forest where the wild pigs hid, the rich tropical greenery that covered the floors and walls of our deep valleys—canceled out everything else we did. And by a wide margin. Was our forest really so much more important than our emissions?

No and yes. The fundamental predicament of climate change is one of timing and placement. Carbon in our atmosphere has, because of its location, an outsize influence on the temperature of the planet and the ecological chaos we're experiencing as a result. But it's actually a tiny percentage of the carbon that's stored elsewhere on the planet—infinitesimal compared with what's locked in the Earth's crust and mantle and deep ocean, yes, but also just a fraction of the amount of carbon already stored in nature, from forests and algae to peat bogs.

Carbon is said to move in two cycles: There's the slow one—the barely there, eon-scale flux in the carbon stored in the depths of the Earth and ocean—and the fast one, the one that flows at a timescale measurable in the lives of living things. (The two speeds are a bit like the tortoise and the hare, if the hare is running and the tortoise is a long-extinct and forgotten species whose constituent atoms are slowly leaving the world of the living for that of geology.) When we burn fossil fuels, we're polluting our fast world with pieces of the slower one and knocking it out of balance. In the blink of a geological eye, we're returning to the atmosphere huge amounts of carbon that it took nature unfathomable stretches of time to pack safely away.

We know this behavior can't continue. Look at any model of the ways that we might keep Earth from warming more than 2 degrees Celsius (the already dangerous threshold that the Paris agreement was crafted to keep us from crossing), and you will see that there is no path to a stable climate that doesn't include a dramatic reduction in our emissions. We can't keep adding slow carbon to our fast-moving crisis in the living world. There is no confusion about that fact among experts, and it's the reason we talk so much about emissions and the imperative to reduce them.

But there are also important opportunities for change beyond just cutting our use of fossil fuels. All these living things that take in carbon dioxide and turn it into biomass are protecting us through their very existence. When we destroy nature's carbon storage (should we clear-cut all that biomass at Wind River, for instance), we can turn it from a carbon sink into a source, from an ally into yet more fuel for the fires of our era. But what if we were able to help deepen the sinks—to work with nature, to lean into the curve, to help it help us out of a mess of our own making? Nature, too, is an amazing, complex, and remarkably effective technology—our biggest and most overlooked ally in the climate fight.

ONCE A YEAR, JIM LUTZ, A PROFESSOR OF forest ecology at Utah State University, and his students come to Wind River. Within an intricately mapped section of the old forest about the size of 50 football fields, they visit every individual tree and snag and vine over a centimeter in diameter—which is to say, more than 37,000 of them—and record what has died and what has grown, and by how much. This kind of attention to detail is hardly unique among studies at Wind River.

In 2010 it took Lutz and a team roughly 10,000 hours of measuring, tagging, and detailed mapping of trees to set up the plot; the annual forest census takes another 1,500 hours or so. When I ask Lutz what inspired so much effort, he explains that he was pursuing not just a discrete inquiry but "an abiding objective" that would last as long as his career did: a drive to understand the details of how an old-growth forest actually works. When and why do trees die? ("You'd think people would have worked that out by now," he adds.) When and why do they gain or lose carbon? How does their most basic biology react as the world around them gets hotter or drier? "You have questions that can't be answered except with a large number of trees over a large number of years," Lutz says.

Lutz also needed such a vast area to study because he was interested in a relatively rare resident of the forest; to get enough examples of it for his studies to be meaningful, he'd have to cover a lot of land. Lutz's elusive quarry? Thick, old trees like the big Douglas fir that Bible so admired. These days, old-growth forest is itself a rare find, but even within it, the attrition of centuries means that most trees aren't actually that old. As Lutz puts it, "to grow a big tree, you need an old tree, which means a tree has to survive"—not just logging but fires and insects and diseases, and anything else that could have come along during its long life and killed it. Old-growth forest is naturally a complicated mix of ages and sizes and structures. But though truly big trees aren't the most common of the forest's residents, Lutz has learned that their role in its ability to store carbon is as oversized as they are.

In a 2018 paper looking at 48 different forest plots, including the one in Wind River,

_ Last year, the UN Environment Assembly adopted its first ever resolution to conserve and restore peatlands, the largest natural terrestrial carbon store on Earth.

KEN BIBLE HAS STUDIED THE TREES IN THE WIND RIVER EXPERIMENTAL FOREST, A RESEARCH AREA IN SOUTHERN WASHINGTON STATE, FOR MORE THAN A QUARTER CENTURY.

he found that the largest 1 percent of trees contain fully half of all the above-ground live biomass, which also means half of all the carbon, since the two are directly correlated. Young trees sequester carbon faster, packing it on in the vigorous growth of their early years, but they can't begin to compete with what large trees have been able to build into their trunks and branches through years and years of maturation. "You can't sequester a lot of carbon without big trees," Lutz says. "You just can't do it."

This makes old trees—and even Munger's much-hated dead trees and logs, which can take centuries to rot in the Northwest—not useless but precious. While a single-age stand would lose 1 percent of its carbon storage if it lost 1 percent of its trees, big trees are so important that a 1 percent loss of individuals in an old forest could reduce its carbon by half. And while old forests eventually begin to reach an equilibrium, at which they're not adding a lot more carbon than they're losing through death and decomposition, researchers have found that the old growth in Wind River is still sequestering new carbon each year, adding to the huge amount it already stores. "Even just putting a thin annual growth layer on such a big cylinder is a huge deal," explains Ben Vierra, who manages NEON's research in the Pacific Northwest. Bible, deep in the grove, says: "This forest is still putting on forest. Quite a bit actually—it could give a young forest a run for its money."

There has recently been much discussion of tackling climate change by planting lots and lots of trees, something that Lutz is all for—it's still carbon, after all. But he's cautious about how much can really be stored by a lot of willy-nilly new planting, especially if those trees are planted in conditions that will not allow them to thrive and grow old.

Methods for optimizing nature's ability to store carbon are known as natural climate solutions. The word *natural*, it turns out, is as key as the word *solutions*—these are strategies that have a lot of potential, but that also work in complex ways that can be difficult for us to understand and re-create. That program I used to figure out the park's carbon footprint in Hawaii back in 2008? Its calculations for carbon storage in landscapes were so new, and still so unsophisticated, that some parks didn't yet bother to report them. (Depending on how I defined the *type* of forest we had—it was a mix, but in the program I had to choose between "wet tropical" or "dry tropical"—the amount of carbon that the program credited the park with removing from the atmosphere could nearly double.) It's not that forests and other natural areas can't store a lot of carbon—they're currently storing much, much more than is in the atmosphere, including both what's there naturally and what's human-added—it's that carbon moves through them in complicated ways that are hard to measure. How do you account for the natural release of carbon when plants rot? For the widely differing amounts of carbon that different ecosystems hold in soils? For the ways that climate change itself is affecting the way that plants' biology works and how much carbon they can store?

You may have seen last year's ecstatic headlines that planting a trillion trees could "stop" climate change (or the recent endorsements of the idea by the World Economic Forum and the Trump administration). In fact, the paper in question simply asserted that many new trees could offset more than 200 gigatons of emissions, and it was followed by a series of responses from other scientists who argued that the authors had, pretty dramatically, overestimated the carbon storage potential of new trees. (The authors of the original paper stand by their results.)

Some tree-planting schemes envision planting them in places they do not naturally grow, which brings up a host of complications, such as the risk that fire or other local disturbance regimes could destroy new trees and negate any carbon gains, or that covering naturally light-colored or reflective landscapes, such as grasslands, with dark-colored trees could actually warm the Earth faster. Well-meaning tree planters also have to consider that some of the ecosystems the theoretical new plantings would replace are already sequestering sizable amounts of carbon. Forests get lots of attention, but they're hardly our only options for natural carbon sequestration. Intact grasslands, for example, store enormous amounts of carbon in soil, safely away from fire. (However, grasslands are steadily being converted for agriculture.) Peatlands, though they make up only 3 percent of the world's land, sequester more carbon than any other type of terrestrial vegetation. And yet we're constantly draining and drying them to convert the land to other uses, such as oil palm plantations. When Indonesia's desiccated peat swamp forests burned in 2015, the region emitted more carbon each day than did the entire European Union.

Natural climate solutions are best approached holistically—a chance to support nature in the work it's already doing. That can mean focusing on the conservation and restoration of ecosystems that we know can hold lots of carbon but which are disappearing rapidly: peatlands and grasslands and forests, but also mangroves, sea grasses, and salt marshes. In agriculture, which can strip soils of much of the carbon they once contained, it can mean using grazing and tilling and cover cropping practices that conserve carbon, or adding more carbon with biochar, a soil amendment made with a kind of charcoal. For forests, easy solutions include focusing on reforestation (planting or simply allowing regrowth in places where trees have been lost) or proforestation (a fancy term for protecting existing forests that might otherwise be cut down) and being thoughtful about afforestation (putting new trees where there were no forests previously). It can even mean managing timberlands to store more carbon. If you cut fewer trees from a stand or cut stands less frequently, you can still produce wood while keeping carbon on the landscape. (In some cases, carefully managed thinning can actually increase carbon sequestration, because it allows remaining trees the chance to grow large.) In the Northwest, Douglas fir plantations are commonly cut every 35 to 40 years, to maximize profits. But it's well known, thanks in part to early studies at Wind River, that letting trees live to 80 or 100, while potentially less lucrative, produces more wood and sequesters more carbon.

Sea Change

Oceans make up 71 percent of Earth, and give us food, work, and a habitable planet. They also absorb 90 percent of the excess heat trapped by greenhouse gases and about 30 percent of all CO_2 released into the atmosphere. For that they get: acidification, less oxygen, dying sea life. Three things that could help:

1.
According to Janis Searles Jones at Ocean Conservancy, we will lose nearly all coral reefs if temperatures rise by 2 degrees. At the Florida Aquarium in Tampa, scientists are working to make coral more resilient; they've successfully bred the endangered pillar coral for the first time in a lab. And the Florida Fish and Wildlife Conservation Commission is preserving coral specimens to preserve biodiversity—like a seed bank for corals.

2.
Warming waters are driving fish species to relocate. So scientists at Rutgers are developing models to see how fish stocks will change in the future, to help fisheries and communities adapt.

3.
Committees in the House and Senate passed the Climate-Ready Fisheries Act of 2019 to help fishing communities. And the House passed the COAST Research Act to support expanded research and monitor ocean acidification.

Searles Jones says, "To bring the ocean to the climate fight, we need you and all your friends. Your elected officials need to hear from you."

Mark Harmon, a forest ecologist at Oregon State University who has been researching carbon storage in forests since the 1970s, tells me that he's lately been hearing more people use carbon sequestration as a justification for doing the opposite: cutting more trees, faster, so you can plant a new generation more quickly. The theory is that carbon is quickly sequestered in plantations and then stored in wood products, rather than wastefully lost to decomposition in older, slow-growing forests. (Sound familiar?)

Harmon sees this as a fundamental—and frustrating—misunderstanding of how carbon works in forests. Young trees take up carbon quickly, sure, but they're starting from a huge carbon deficit if a bunch of older trees had to make way for them. The old-growth section at Wind River holds up to 400,000 kilograms of carbon per hectare and is still adding more. Cut the forest "and it becomes a huge source for a long time," Bible says.

It's the total storage that matters, explains Harmon: "That's what the atmosphere perceives." It's also an outcome for which we can choose to manage our timberlands. In the future, we're likely to manage tree plantations for carbon sequestration as well as for wood products, Bible believes, and that's more likely to happen if we finally put a price on carbon. To do otherwise would be to turn our backs on an offer of help when we need it most.

There's still a lot we don't know about how the natural systems that sequester so much of our carbon operate, or how they will respond as the world changes around them. Some of these changes may be significant. More carbon dioxide in the atmosphere, for example, means that some trees may sequester carbon faster, but warming also leads to problems like drought stress and increased wildfire, which mean more carbon escapes. When a strong El Niño hit the Pacific Ocean in 2015, nature stored only about 44 percent of that year's human emissions, compared with 66 percent during a colder La Niña in 2011.

But we're learning more all the time—at Wind River and elsewhere—about how nature absorbs carbon, how to allow it to absorb more, and how meaningful that help could be. One recent study suggested a suite of land management changes—restoration of degraded forests, wetlands, and grasslands; carbon-sensitive agriculture; better management of timberlands—that if enacted in the US could quickly offset a fifth of our current emissions. Another found that, globally, natural climate solutions could provide as much as 37 percent of the cost-effective carbon mitigation necessary between now and 2030 to keep warming from exceeding 2 degrees Celsius.

"We have to acknowledge," says Harmon, "that natural systems have the capacity to repair things and to help us. We have to take more advantage of them, not less."

BEFORE WE LEAVE WIND RIVER, BIBLE wants to show me another part of the experimental forest. We turn our backs on the giants and follow a slight path around a small wetland and through a grove of alder trees, arriving in a section of forest that has been managed quite differently.

It feels as if I hadn't quite seen the old growth until we walk away from it. It isn't just that this other, much younger section of forest has smaller trees; it also has much less moss, much more light, a totally different understory. Though only a few hundred yards away, it feels unfamiliar, like a different forest type altogether. It's a cliché to say that an old-growth grove feels like a cathedral, but after leaving it, the younger forest makes me think of pictures I've seen of bombed-out churches—sacred spaces suddenly opened to the world, unaccustomed sunlight streaming vulgarly in. "When the wind and dry come through here," says Bible, "it just cuts through like a comb."

This young stand is home to many more trees, per hectare, than the older one we've just left, yet researchers have found that it holds less than a quarter of the carbon. "If we were standing here 100 years ago"—before the forest was removed—"it was exactly like where we just were," says Bible. "It's going to take a really long time to get back to that stage." But he hopes that the foresters of the future will be able to help speed the process.

Munger and his contemporaries would likely be surprised to learn that today's foresters are preoccupied with finding ways to promote the very features that they derided in old growth—dead wood, trees of a variety of sizes and ages, decomposition, large quantities of biomass just standing or lying around—and seeking to re-create them even in the young tree plantations that their predecessors prized for not having those things. New versions of the old spacing research are showing that with targeted thinning and management, you can create old-growth features even in homogenous commercial forests, allowing space for trees to grow to huge sizes in the future. Outside of the old-growth reserve, Bible says, much of the future of experiments at Wind River lies in studying ways to help forests maximize not profit but carbon storage. Munger's "decadent" forests and murderous snags "were systematically removed in the 20th century," write Herring and Greene. "Now they are being systematically returned in the 21st century."

It has occurred to Lutz that his decision to study old-growth forests may seem a bit odd: Why bother to become an expert in a world that is all but gone? But he likes to remind people that the condition of our forests is a choice, a decision that's now more social than natural. In the future we will have only the natural places that we choose to have, only the ones that we value enough to protect and restore and nurture. One day, he says, if people decide they want more of these big, old, complicated forests in the world, "then I can help." And that forest, in turn, can help us.

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_Research in Australia and China suggests that certain types of fungi can be added to soil to enhance carbon sequestration by up to 17 percent.

→ 8% PORTION OF GLOBAL CARBON EMISSIONS PRODUCED BY THE CEMENT INDUSTRY

Blockbuster

_Without concrete, our civilization would be nowhere. With concrete, the planet is suffering. Some clever chemistry can help cure that problem.

BY
Vince Beiser

ILLUSTRATION BY
Jan Siemen

IF YOU FIND YOURSELF AT THIS MOMENT in a city of any size, take a look out the window. Most of what you see is made with a single material, one that dominates our world: concrete. It makes up the bulk of virtually every office tower, shopping mall, highway, and airport on earth. We produce tens of billions of tons of the stuff every year—enough to build a 100-foot wall right around the equator. And that tonnage is certain to grow in coming years, as cities continue to mushroom in China, Nigeria, and other fast-developing nations. Concrete is wonderfully useful, but it comes at a steep cost: The industry that makes it eructs about 8 percent of all annual carbon emissions.

To be precise, it's the production of cement—the glue that binds together sand and gravel to *form* concrete—that is the problem. Or, rather, two problems. To make cement, you put limestone and other minerals in a kiln and bake them at up to 2,700 degrees Fahrenheit. Problem one: The heat for those kilns is typically generated by burning coal or other fossil fuels. Problem two: The heat-generated chemical process that eventually results in the fine gray powder we call cement also generates gaseous carbon dioxide as a byproduct, which gets whisked up into the atmosphere.

Those emissions add up. If the cement business were a country, it would be the world's number three producer of greenhouse gases, trailing only China and the United States. No surprise, then, that researchers and entrepreneurs around the world are working on projects to make cleaner concrete. The most promising are a handful of companies that focus on making the process of manufacturing concrete not only less of a problem but part of the solution.

The current head of the pack is a company named CarbonCure Technologies. It aims to change the chemistry of that sea of concrete slightly but significantly. Headquartered in an aluminum-sided, two-story building in a modest industrial park outside of Halifax, a tiny city dangling off Canada's Atlantic coast in a time zone an hour east of Eastern, CarbonCure's entire staff could fit in a school bus. At the helm is a lean, amiable, 42-year-old engineer named Robert Niven.

Niven grew up on Vancouver Island, with regal forests and rocky beaches for playgrounds. During summers home from college, he worked as a firefighter in British Columbia's remote northern forests and spent as much time as possible rock climbing and whitewater kayaking. As a civil engineering student at Montreal's McGill University in the mid-aughts, he fell into a research program aimed at figuring out how carbon could be used to help make concrete, replacing some of the cement used in the process. The concept wasn't new, but no one had figured out how to do it effectively at scale. Niven looked at the problem through a chemist's lens, researching exactly how it might work at the atomic level.

A year before he graduated, Niven went to a UN conference on climate change in Montreal. He was dazzled by the energy of the 10,000 attendees who swept into the city. But what really hit home was a speech by a representative from Tuvalu, a tiny Pacific island nation. "He gave the most emotional plea for help, saying, 'We're losing our history, our homes, our livelihoods, and our ancestry because of sea level rise,'" Niven says. Suddenly his work felt like something more than just a math problem.

Two years later, Niven moved to Halifax to be with his then-girlfriend, now wife. Her father happened to be a successful entrepreneur with a penchant for niche green projects, like solar-powered marine lights, and he helped Niven see how his ideas could be turned into a business. With that advice—and a little cash—from his future father-in-law, plus $10,000 in leftover student loans, Niven launched CarbonCure in 2007. The concept: develop a system to replace some of the cement used in making concrete with carbon dioxide, thereby

both reducing emissions and sequestering carbon. Not to mention saving money.

Niven and his team eventually figured out a process that takes liquefied CO_2 (captured from places like ammonia and ethanol plants) and injects it into wet concrete as it's being mixed. The CO_2 chemically reacts with the cement and other ingredients in the mix, remineralizing it into solid calcium carbonate, which helps bind the other ingredients, increases the concrete's compressive strength, and takes the place of some of the cement that would otherwise be required. And even if the concrete eventually gets pulverized, that carbon remains an earthbound solid.

The company has developed a surprisingly simple system to bring the whole process out into the field. A tank of carbon dioxide feeds into a pair of dorm-fridge-sized metal boxes stuffed with valves, circuitry, and telemetry gear, which regulate the carbon dioxide's flow into a hose, which sprays it into the mixing drum. (The boxes are all made by a few guys in jeans and T-shirts at the Halifax HQ.) The tricky part is figuring out the optimal dose of CO_2 for different mixtures; the strength, weight, and appearance of concrete for an airport runway in northern Canada are not necessarily what you want for an office building wall in Southern California. At the Halifax headquarters, CarbonCure technicians keep an eye on a wall of monitors tracking the operations of every one of their machines out in the real world. The monitors let them know if, say, a valve gets blocked at a job site in Georgia or a tank starts running low in Singapore.

> Simplicity is one of the best selling points. "The whole system fits in a crate," Niven says. "It takes a single day to set up and it's universally applicable to any concrete plant in the world."

The simplicity of its system is one of CarbonCure's best selling points. The concrete makers who are its customers don't have to change much for mixing and pouring at a construction site—they just add a little extra hardware. "The whole system fits in a crate," Niven says. "It takes a single day to set up and it's universally applicable to any concrete plant in the world." CarbonCure also connects clients to suppliers of captured carbon from other dirty manufacturing processes. (The company's goal is to someday capture carbon from cement plants themselves.)

CarbonCure's tech has improved steadily over the years, and so has its profile. In 2018 the company was named one of 10 finalists for a $20 million XPrize for turning carbon into commercial products. (The contest's winner will be announced this fall.) That same year, the company got a sizable (Niven won't say how sizable) investment from Breakthrough Energy Ventures, the billion-dollar fund focused on carbon-reducing investments backed by Bill Gates and other tech titans. The money helps, Niven says, but the stamp of approval is perhaps even more valuable. "It really meant something for the broader investment community that that group would say, 'This one's a vetted winner,'" Niven says.

Today CarbonCure says that more than 200 concrete makers across North America and in Singapore are using its system. A new building on LinkedIn's Silicon Valley campus, a stretch of road in Hawaii, and an aquarium exhibit in Atlanta all include CarbonCure-treated concrete. Its technology has been used in the making of more than 4 million cubic yards of captured-CO_2 concrete, saving some 64,000 tons of emissions, according to the company.

But in the big picture, CarbonCure's impact is still pretty small. In a few cases, customers have been able to reduce their cement use by 20 percent—but the average is closer to 5 percent.

The best news, then, may be that CarbonCure has a growing crowd of competitors, including three of the other finalists for that XPrize. One rival, New Jersey–based Solidia, uses a similar concept and seems to get even better results, but as of February, it makes only prefabricated concrete blocks. (The construction industry mostly uses concrete mixed at job sites.) Another, Alberta's Carbon Upcycling Technologies, combines gaseous CO_2 with fly ash—a waste product from coal-fired power plants—to create nanoparticles that can replace about 20 percent of the cement in a concrete mixture. Cofounder and CEO Apoorv Sinha says he hopes to eventually double that percentage, and to start selling to his first customers this year. Meanwhile, researchers at Rice University claim to have developed a concrete mix that primarily uses fly ash as the concrete binding agent—no cement required. Other outfits are attacking the problem from different angles. A group of MIT scientists and an Australian company are developing new, lower-emission ways to make cement powder.

Most of these projects haven't made it to market. Securing funding is difficult, and the customer can be too. The construction industry is notoriously chary about adopting new ways. With good reason: You can't afford to "fail fast" or "iterate on your product" when your product is a skyscraper or a dam. To truly decarbonize all that concrete will probably take some kind of government help to make these methods more commercially attractive. But CarbonCure's success offers a proof of concept: There's a concrete business case for better cement.

VINCE BEISER *(@VinceBeiser) is the author of* The World in a Grain: The Story of Sand and How It Transformed Civilization. *His last story for* WIRED, *in issue 28.01, was about catfishing from prison.*

_A US tax credit for carbon storage passed in 2018 could spur retrofits of power plants that would in turn capture 54 million tons of carbon per year by 2030. That's the equivalent of taking some 10 million cars off the streets.

A Better Build

BY Liz Stinson

CONCRETE DOMINATES CONSTRUCTION, BUT SOME ECO-FRIENDLY MATERIALS ARE TRYING TO CHIP AWAY AT THE EDGES.

CROSS-LAMINATED TIMBER

Made from lumber boards that are glued and layered on top of each other crosswise, CLT comes in giant panels that can replace concrete and steel as the backbone of a building. When produced with sustainable forestry practices, CLT is a green alternative. The material was used to construct what is currently the world's tallest timber building: Norway's 18-story Mjøstårnet tower.

HEMP

Combining the cannabis strain's woody interior pulp with lime and water produces "hempcrete," a drywall-like material that's light and robust and has a low carbon output. Hempcrete isn't load-bearing, so it won't replace concrete and steel, but it's already been used in residential projects for walls and insulation.

MYCELIUM

When the threadlike fibers of mushroom root extensions are mixed with byproducts like corn husks, sawdust, and rice straw, it creates a foamlike material that can be cast into panels, bricks, and tiles. Often used to replace Styrofoam packaging, mycelium materials have also been used to make acoustic panels and insulation. One architecture firm in Cleveland is experimenting with combining mycelium with wood, insulation, and other construction waste to create biodegradable bricks.

Emission Control

A tax to slow the release of carbon gains momentum.

BY Matt Simon

FOR DECADES, THE IDEA OF A CARBON tax has been stuck in the waiting room of American politics: Familiar to everyone who comes and goes, it has sat there long enough to grow cobwebs from its ears. For the vast majority of Republicans, the idea is anathema, and for Democrats it's one among several policies that compete for the love of lawmakers and climate wonks.

But politics, like the climate, is volatile these days. In the past couple of years, some Republicans have broken ranks with their party to support a tax on carbon emissions—perhaps because the climate is becoming more salient with voters, perhaps as a foil to the more radical Green New Deal, or perhaps to, you know, do something to stop global warming. Given that tiny bump in bipartisan momentum, it's worth revisiting the case for a carbon tax.

If you want to discourage bad behaviors, economists say, make them expensive. The strategy works for cigarettes, soda, gasoline. And it works for carbon emissions too. Adding a charge to the carbon content of fossil fuels is widely seen as one of the more powerful tools a country can use to shrink its emissions.

It works like this: A government charges a fee per ton of greenhouse gases emitted. The fee is small at first, rising gradually to give companies a chance to adapt. Individual households don't get taxed directly, but they could take a hit when the big emitters raise their rates in response.

"The beauty of a carbon tax is that everything we want consumers to do gets incentivized to be done," says MIT economist Christopher Knittel. Residents pay more attention to their thermostats. Utilities might invest more in solar or wind farms. Manufacturers could start offering more energy-saving products, such as more efficient cars and heating and air-conditioning systems.

Several countries have implemented some form of carbon pricing—just not the most-offending nations. After Sweden instituted a tax in 1991, its transportation emissions fell an average of 6 percent a year, according to one study. (A separate tax on transport fuels shrank the country's carbon footprint further.) In British Columbia, a carbon tax reduced emissions by up to 15 percent. Last year, after the province's experiment proved successful, Canada expanded carbon pricing nationwide. Researchers at MIT calculated that if the US placed a $50-per-ton tax on carbon and increased the tax 5 percent per year, emissions would drop 63 percent by 2050. If every country adopted a carbon tax with a similar effect, the world might be able to slash its emissions in half by the middle of this century.

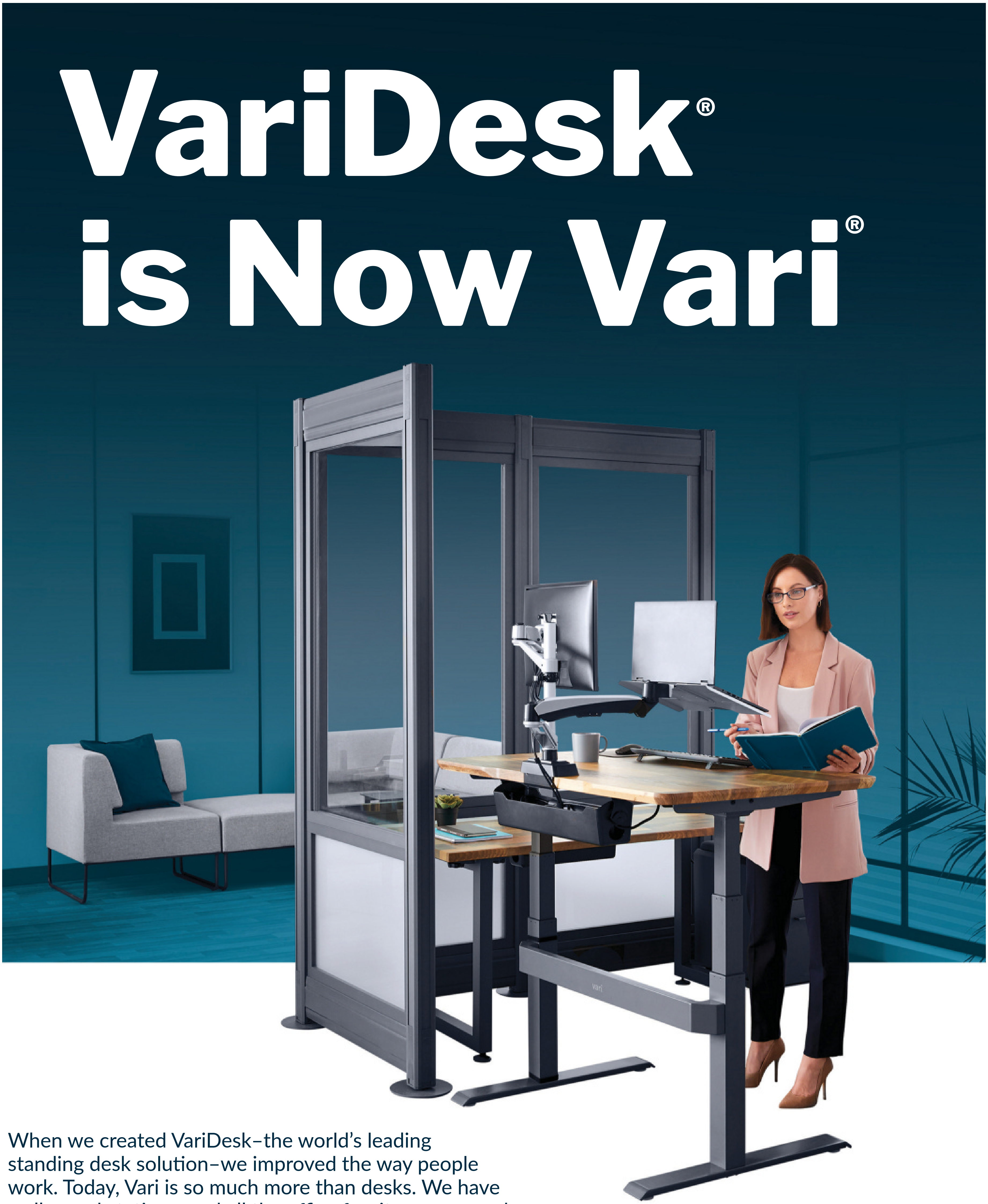
The idea that has lately taken off among certain conservatives is one that cuts the sourness of a carbon tax with some sweeteners. US representative Francis Rooney, a Florida Republican, has cosponsored legislation that would impose a fee on metric tons of carbon emitted and then distribute the spoils back to US residents as a monthly "carbon dividend." (You could think of it as a form of basic income, the concept that helped make Andrew Yang one of the biggest gang leaders in America over the past year.) In one proposal, crafted by the bipartisan Climate Leadership Council, a family of four might expect to get $2,000 back in the first year. Plans put forward by Rooney and the Climate Leadership Council also propose to eliminate or suspend federal regulations on carbon emissions—which perhaps helps explain why the CLC has the support of oil giants, car manufacturers, and utility companies.

Ultimately, a carbon tax needs to be global to reach its full potential. After all, heavy-emitting industries can flee to nations that have no carbon pricing. Placing a carbon tariff on goods imported from such places can incentivize dirtier countries to clean up their acts. The European Union is now considering such a measure. Revenue from that kind of tariff could again help fund a dividend, to shield people from rising costs.

All good ideas, but none too likely to pass during the current US administration, which has pushed tax cuts and denied the severity of climate change. Campaigns to implement one in Washington state have failed twice. There are other options. Mark Jaccard, an economist who helped design British Columbia's carbon tax, argues that a country can tighten regulations instead, choosing to phase out coal plants, for example, or implement a low-carbon fuel standard. Regulations "may be way better politically, like way better, and only slightly less efficient economically," Jaccard says. The key to saving the world? It's all politics.

MATT SIMON *(@mrMattSimon) is a senior writer at* WIRED.

_ A survey suggests that two-thirds of Americans support a carbon tax if the revenue is used for environmental restoration.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"All of the most promising routes to decarbonization, every last one of them, require that humans change beliefs and behaviors with which they may identify." page 54

Nourish

HOW WE'LL FEED—AND SAVE—THE PLANET

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→17% PORTION OF GLOBAL ELECTRICITY USE THAT GOES TO REFRIGERATION

Chilling Effect

_Refrigeration revolutionized the global food supply—and accelerated global warming. Now the future of cooling could be in the hands of an ex-poultry farmer.

BY Nicola Twilley

ILLUSTRATION BY Jan Siemen

BACK IN 2001, A MIDDLE-AGED MAN made a video of his car and sent it around to a few friends. So far, so predictable—but this video featured a dilapidated Vauxhall Nova whizzing around a junk-strewn yard in a cloud of fog. At the wheel was Peter Dearman, a rumpled-looking autodidact who had spent the better part of four decades imagining a way to build engineering's ultimate vaporware: a motor powered only by air.

Born in 1951 on an egg farm north of London, Dearman would seem an unlikely candidate to have solved the problem. He left school at age 15 and worked in the family business for a while, then took a job at a local sheet-metal factory. He spent his evenings as many Englishmen do—out in the garage or the garden shed, tinkering. But Dearman's aptitude and ambition set him apart from other hobbyists. Over the years he filed patents for an improved adjustable wrench, a solar hot-water system, and a portable resuscitator that is still used in ambulances today. His most impressive achievement, however, was the Nova, whose engine he cobbled together from string, a used beer keg, a red plastic trash bin, and a coffee can's worth of liquid nitrogen.

The idea behind Dearman's project dated back to at least 1899, when a Danish inventor named Hans Knudsen claimed to have designed an automobile that could run on "clear, bluish" fuel—liquefied air, to be sold at a penny a gallon. Rather than spewing out a toxic mix of pollutants and greenhouse gases, it would leave a harmless trail of condensation in its wake, wafting by at the stately speed of 12 mph. Knudsen received admiring media coverage at the time, but his company went belly-up in a matter of years. Modern cynics suspect he was engaged in a Theranos-style fraud, in part because no one could figure out how he'd done it. For years, a working liquid-air engine seemed about as fanciful as a perpetual motion machine.

Still, the underlying principle was sound. Most engines rely on heat differentials. In the case of, say, a gasoline-powered car, the fuel is mixed with air, crammed into a piston chamber, and set alight, causing it to jump more than 1,000 degrees in temperature. The gas rapidly expands, propelling the piston and, in turn, the wheels. Take the same process, slide it way down the Fahrenheit scale, and you've got a liquid air engine. The nitrogen fuel starts out at 320 degrees below zero. When it enters the (much warmer) piston chamber, it boils off into gas. The change in temperature is smaller than with gasoline, so the pistons move with a little less oomph—but it's enough to get the wheels going. The real problem comes later: All that frigid fuel coursing through the engine quickly freezes it, effectively wiping out the heat differential. The air stops expanding, and the car runs out of puff.

The roadblock was clear, Dearman told me recently. He'd been pondering how to get around it since he was a teen. In a car that runs on heat, you need something to keep it cool—a radiator. In a car that runs on cold, you need the opposite. "I had an idea in my head for how to make it work, but I knew I wasn't going to get anywhere until I had some research to go on," he said.

The breakthrough came in 1999. Dearman was watching an episode of the BBC's dearly departed flagship science program, *Tomorrow's World*, in which the presenter visited the University of Washington to report on a rather clunky-looking converted mail truck. It had trouble with hills, and its top speed was 22 mph, but it ran on liquid nitrogen (a profligate 5 gallons per mile). Invented by Abe Hertzberg, an eccentric professor who had previously come up with a laser-powered airplane, the truck boasted one major innovation. Before the freezing-cold fuel reached the engine, it ran through a heat exchanger, a series of concentric tubes that circulated outside air around the fuel line. John Williams, who worked on the truck as a graduate student, explained that the exchanger ensured "the whole thing didn't turn into a giant ball of ice." But it didn't tackle the fundamental problem—that the liquid nitrogen still rapidly cooled the engine, throttling its own expansion into a gas. "Our project was a proof of concept," Williams explained. "We were reconciled to a certain degree of terribleness."

From his sofa in the historic market town of Bishop's Stortford, Dearman immediately saw both the logic of Hertzberg's design and a way of improving on it. The answer to making sure the nitrogen continued expanding? Antifreeze. "It's obvious, but it's only obvious once you've seen it," Dearman said. He went out into his garage, grabbed a blue plastic jug from the shelf, and started playing around with his lawn

Tech We Need

Silicon Valley, if you're listening, here's how you can help:

- Lab-grown Thanksgiving dinner for 12, complete with the wishbone.
- Waterless dishwashers.
- Biodegradable cling wrap.
- A smart pantry that serves up recipes for soon-to-expire ingredients.

mower, hacking its engine to squirt a mixture of antifreeze and water into the piston chambers on each stroke. This brought ambient heat directly to the place it was needed most—and the engine's efficiency skyrocketed. The same trick worked on the battered Nova, bought as a guinea pig.

And there things might have ended if Dearman's brother, a contractor, hadn't mentioned the Nova to a wealthy client, who put up funding for a patent application. In 2004, the client also introduced Dearman to Toby Peters, a former war photographer turned business strategist who had been working on corporate social-responsibility initiatives. Peters was skeptical, so he took the engine to the University of Leeds for a full workup. The science checked out. The Dearman engine was about as efficient as its gas- and diesel-powered counterparts; roughly a third of the energy in the fuel was actually put to work, and the rest went to waste. But no amount of antifreeze would solve the underlying issue: Gallon for gallon, liquid air contained far less energy than fossil fuels. It would never supply as much torque and horsepower as car buyers demanded.

Then, in 2011, Peters had an epiphany of his own. Thinking of the Dearman engine purely as a source of locomotive power missed its unique selling point. Where a typical engine lets off waste as heat, Dearman's vented it as cold. And cold, Peters told me, is "immensely valuable." What the newly formed Dearman Company was trying to sell, in other words, was not so much an engine as a mobile cooling unit. That meant it had plenty of prospective customers waiting behind the wheels of refrigerated trucks.

The sales pitch wrote itself: Rather than relying on diesel-powered units, which warm the world with greenhouse gases and clog pedestrians' airways with asthma-inducing particulate matter, customers could upgrade to a Dearman, which would emit only nitrogen. What's more, it would cost the same to operate as a conventional system, while being quieter to run, quicker to refuel, and faster to cool down. Yes, making the liquid nitrogen would consume energy—but even when you factored that in, the Dearman engine would result in an emissions savings of about 40 percent over diesel. If the grid powering the fuel plant was running on renewable energy, the figure rose to 95 percent.

The logic was impeccable, but would winning the argument be enough? History is full of examples of clever new technologies that never found their market, either because the timing was wrong or the branding was bad or a company with deeper pockets flooded the playing field with a rival product. Capitalist economies are generally imagined to operate according to the laws of natural selection: The fittest survive, and the rest go the way of the Betamax. In practice, though, the outcome is rarely so meritocratic. At the dawn of the age of domestic refrigerators, for instance, there were two competing designs—one powered by electricity, the other by gas. Even though gas fridges were quieter and less expensive to operate, electricity won out. Big companies threw their prodigious ad budgets behind it, and consumers did as they were told. If Dearman and Peters were going to remake the cold chain, the temperature-controlled network through which food travels around the globe, they'd need more than a really good idea.

The journey from garage prototype to commercial appliance was a long one. Peters focused on fundraising and business development; Dearman worked alongside his son and a growing team of engineers to refine his original design and make it increasingly efficient, compact, lightweight, and dependable. By 2015 a truck equipped with a Dearman refrigeration unit was racking up miles around Warwickshire, undergoing testing to make sure that what worked in the controlled conditions of the lab held together on the rain-slicked, potholed roads of the real world.

A year later, Sainsbury's, the UK's second-largest grocery chain, borrowed a Dearman unit for a three-month trial, shuttling goods from its depot in Essex to London-area supermarkets. A year after that, a Dearman-cooled truck spent six months delivering pints of Ben & Jerry's across the Netherlands for Unilever, without losing a single load.

There were 3 million refrigerated trucks on the road worldwide, and the fleet was expected to grow to 17 million by 2025. Peter Dearman's invention seemed like a shoo-in replacement for diesel. Before too long, even the Royal Society, Britain's most esteemed scientific body, was inviting him to pop round for dinner.

TO THE MODERN EATER, IT CAN BE difficult to grasp just how much, and how quickly, mechanical cooling has transformed both the human diet and the global climate. The technology made its commercial debut only after the Civil War; its earliest adopters were German-born brewers in the Midwest, looking to keep their lager caves chilled in the steamy summer months. But it wasn't long before other industries realized that refrigeration could be used to manage one of humankind's oldest anxieties: food spoilage.

For millennia, people and microbes have been engaged in a form of interspecies warfare. Bacteria and fungi attempt to colonize our food, and we, in response, attempt to delay their advance using an arsenal of preservation techniques. In what was likely a long and slow process, pursued through trial and error, different communities developed different methods for stopping the rot. Some proved quite delicious—stinky cheese, smoked salmon, salami, miso, marmalade, *membrillo*. Even the gelatinous pleasures of Scandinavian *lutefisk* or Chinese century eggs have their devotees.

Most of these preserved foods are incredibly long-lasting, as well as portable. What they are not, however, is the same as fresh: The chemical and physical transformations

_Methane emissions burped out by cows could be cut by 99 percent if farmers changed 2 percent of the ruminants' diet to seaweed.

required to vanquish microbes inevitably also alter the food's original flavor, texture, and appearance. The introduction of widespread, on-demand refrigeration changed all of that, overturning thousands of years of dietary history.

The earliest mobile mechanical cooling units were patented in 1939 by Frederick McKinley Jones, the first African American to receive the National Medal of Technology. Like Dearman, he was a high school dropout and self-taught engineer. Prior to his invention, perishable foods such as meat, dairy, and produce had to be entombed beneath a thick layer of hand-shoveled ice for transportation. In the early decades of the 20th century, a railcar full of California-grown cantaloupes destined for New York City would be packed in 10,500 pounds of ice—and re-iced with another 7,500 pounds several times during its multiday journey. Even then, shipments experienced considerable shrink. Indeed, the impetus behind Jones' invention was the loss, by his boss' golfing buddy, of an entire cargo load of raw chicken. It had to be tossed when the truck carrying it broke down and the ice protecting it melted.

During World War II, the Defense Department quickly seized on Jones' diesel-powered devices, sold under the brand name Thermo King, to supply troops with everything from blood plasma to frosty Coke. In the years afterward, refrigerated trucks transformed the American foodscape. Regional distribution networks gave way to national ones. Slaughterhouses and processing facilities grew increasingly enormous and more remote, driving down the cost of meat and making it an everyday staple. Agriculture became concentrated in those places where a particular crop could be cultivated most cost-effectively, with the result that California now grows half of the fruits and vegetables eaten in the United States.

Today, in fact, more than three-quarters of everything on the average American plate is processed, packaged, shipped, stored, and sold under refrigeration. It is the reason orange juice, stockpiled in giant tank farms, tastes the same year-round, like soda. It is the reason many tomatoes, genetically tuned to maximize cold tolerance rather than flavor, taste like nothing at all. Refrigeration has made us taller and heavier; it has changed the composition of our gut microbes; it has reshaped our kitchens, ports, and cities; it has reconfigured global economics and politics. In 2012, six years before the Royal Society feted Dearman and his engine, the academy's distinguished members declared refrigeration the most important invention in the history of food and drink—more significant than the knife, the oven, the plow, and even the millennia of selective breeding that gave us the livestock, fruits, and vegetables we recognize today.

But as the cold chain has expanded, distributing artificial perpetual winter across the world, it has wreaked havoc on the natural cryosphere, the glaciers and icebergs and frozen swaths of tundra that help keep Earth's climate system in check. Refrigeration already accounts for about a sixth of humanity's electricity usage, and the demand is only expected to grow as countries such as China and India busily build US-style systems of their own. In the next seven years, analysts predict, the global refrigeration market will quadruple in size.

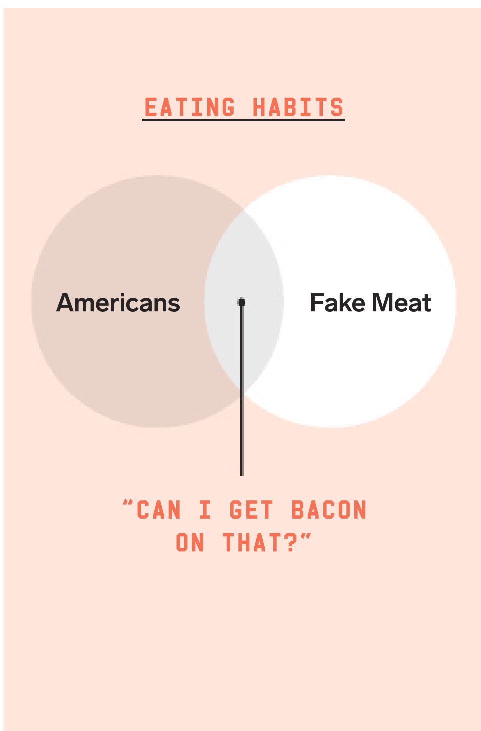
More cooling—of the conventional kind, at least—means more warming, and not just because of runaway power consumption. Refrigerant leaks are a problem too. Once released into the atmosphere, many of these chemicals contribute to climate change. The most up-to-date domestic refrigerators lose less than 1 percent of their refrigerant every year, but commercial refrigerated warehouses can leak up to 35 percent. Different systems use different refrigerants, some of which, like ammonia, have a negligible effect on the climate. But others, like hydrofluorocarbons (HFCs), are known as "super" greenhouse gases because they are thousands of times more warming, molecule for molecule, than CO_2.

Although HFCs are gradually being phased out under the terms of a global agreement signed in 2016, their use is still on the rise in developing countries. That's partly why Project Drawdown, a climate change mitigation initiative founded by the environmentalist Paul Hawken, lists "refrigerant management" as the single most effective solution to global warming. (The category includes those chemicals used to chill people as well as food: Air-conditioning and refrigeration rely on the same technology, and their usage is rising in lockstep.)

And if we do nothing? Suddenly the slogan of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers begins to sound more like a threat than an assurance: "Shaping Tomorrow's Environment Today." Preserving food for a planetary population of 9 billion using existing technology would deliver on that promise in the most disastrous manner. And yet, in the 81 years since Jones patented the

Chartgeist

BY Jon J. Eilenberg



_Solar panels can be placed over lettuce crops, producing gigawatts of energy without killing the salad.

Thermo King, there has been remarkably little innovation in the cold chain—or there wasn't, anyway, until Peter Dearman.

FOR A MOMENT LAST YEAR, IT APPEARED that the curse of the liquid-air engine might not be broken after all. The Dearman units were working well, but the company had burned through its investment capital and was struggling to pay its bills. By early December, it had entered receivership. All was not lost, however: In January, a Denver-based angel investor named Thomas Keller swooped in and bailed the company out.

According to Keller, the firm's problems were "standard issue" for a technology startup. "Dearman had so many opportunities—so many inquiries, so many ideas for where the technology would be helpful—that it ran off in many different directions, all of which were costly," he told me. His plan now is to simplify. He intends to focus entirely on finishing the next-generation engine. "It should be available for Unilever trucks this year," he said.

Still, Keller seemed daunted by the challenges to come. Besides scaling up its manufacturing operation, a huge obstacle in itself, the company will have to hire a sales force, establish maintenance facilities, and develop a supply chain for spare parts. That entails either raising enough capital to build the infrastructure from scratch or partnering with the competition—an old-school refrigerated transportation company—in order to piggyback on its existing networks. "We're struggling a bit with that, frankly," Keller said. "And so we're right back where Dearman was, with just a little pressure added."

Toby Peters, who now works at the University of Birmingham, remains hopeful that the company will navigate past its latest financial roadblock. But he pointed out that, even if all 3 million of the world's refrigerated trucks were retrofitted with Dearman engines, that would not be nearly enough to save the world from refrigeration's catastrophic climate impact. "We are going to be deploying somewhere between 13 and 18 cooling devices per second for the next 30 years, and we're still not going to deliver cooling for all," Peters said. Moreover, he added, "we simply can't green that volume of electricity." Consider refrigeration's human analog: In 2017 and 2018, enough new room AC units were installed in the developing world that their combined energy demand exceeded the total amount of solar power generated globally.

Fortunately, the fix for the fossil-fueled fridge isn't limited to building a better fridge. There are other methods of food preservation waiting in the wings, some new, some old. In Santa Barbara, California, a company called Apeel has devised a high-tech edible coating that slows the metabolism, and thus the decay, of fruits and vegetables. Made from a waxy substance found in avocado pits, it extends produce life by nearly the same factor as refrigeration, while retaining more nutrients and flavor. In Australia, engineers recently announced an alternative to pasteurized milk, one of the most wasted foods in the United States. By using high-pressure processing—roughly 75,000 pounds per square inch, or the equivalent of stacking six elephants on a dime—they were able to make milk stay good for four times as long, without sacrificing taste. A Dutch designer named Floris Schoonderbeek, inspired by traditional root cellars, recently created the Groundfridge, a naturally cooled pod that can be buried in a backyard and filled with 20 refrigerators' worth of food. In Hokkaido, Japan's northernmost island, agricultural warehouses are cooled with last winter's snow. Chefs in Tokyo say the rice, asparagus, and beef that come from the region taste sweeter than their conventionally chilled counterparts.

All of these solutions offer improvements over mechanical refrigeration, not just in terms of climate impact but also in food quality and safety. But all of them are also piecemeal. A coating that keeps room-temperature blueberries plump and juicy for a month does nothing for milk. The ingenious snow-cooled meat lockers of Hokkaido wouldn't work in Santa Barbara, nor would a city dweller have anywhere to bury a Groundfridge. With conventional cooling, the answer to the question "Will it work?" is always a resounding yes. With these alternative methods, the reply becomes more wishy-washy: "It depends."

And "it depends" is not usually the answer we're looking for. There's something reassuring about the one-shot solution, as opposed to the nuanced thinking required to apply local, circumstantial fixes. In some ways, mechanical refrigeration only became a problem because it became *the* answer to perishability. Once we had that particular hammer, everything looked like a nail. This hegemonic tendency—call it technological lock-in, confirmation bias, or just convenience—is understandable, but it's worth resisting. Given that single-solution thinking is what got us into trouble in the first place, we probably shouldn't replicate it in our prescriptions for the future.

It's likely too late for a refrigeration redo in the developed world, unless Peter Dearman can build a Nova capable of time travel. But our blueberries, eggs, milk, and carrots might yet stage an escape from the fridge, at least along part of their journey from farm to fork. In the meantime, we should work to ensure that those parts of the globe not yet bound by the cold chain approach food preservation as a problem with more than one solution. We can't—and shouldn't—pull the plug on refrigeration altogether, but it's not the only weapon in our age-old war on rot.

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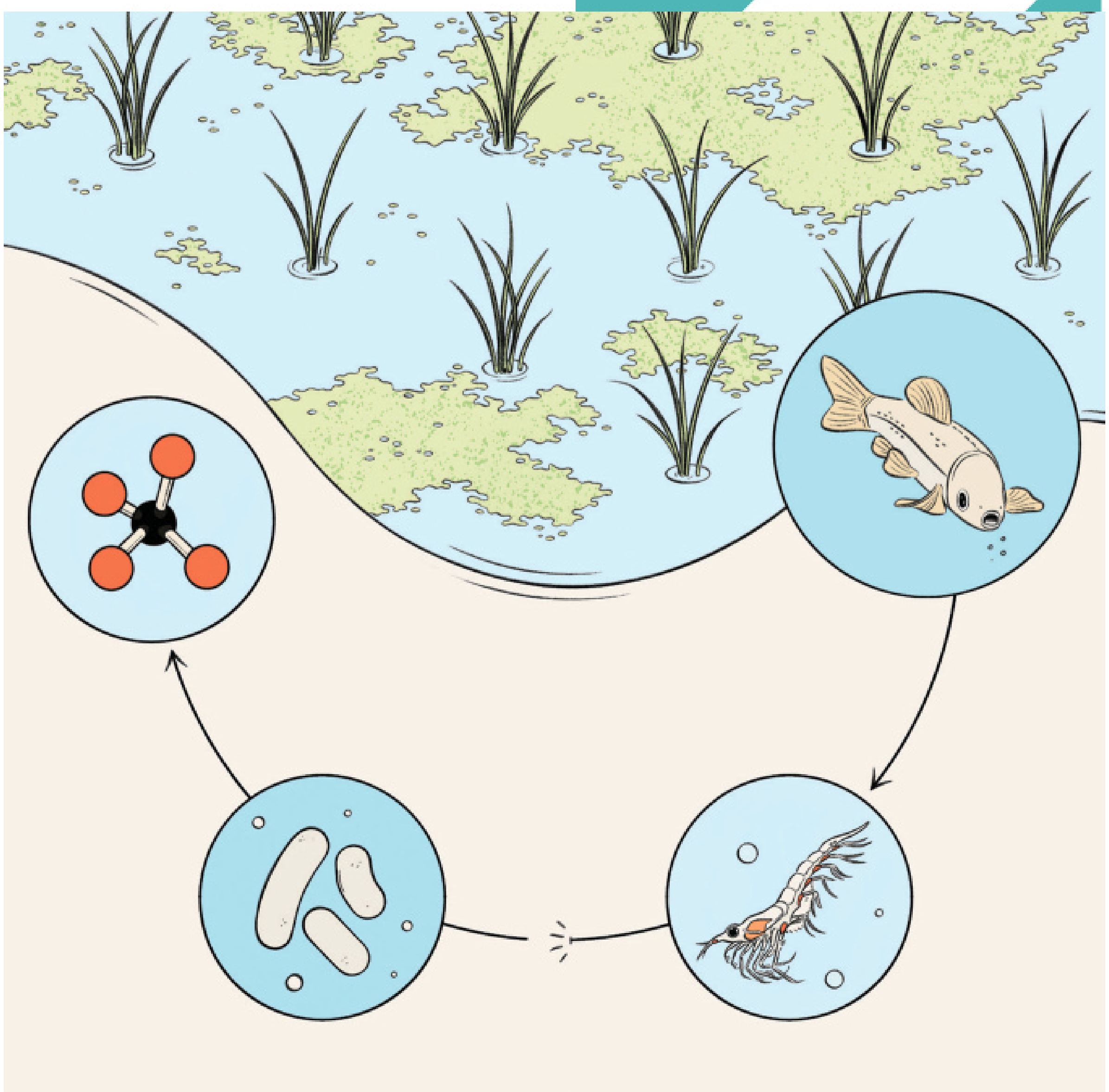
_More than 2,200 "climate victory gardens" have cropped up across the US, part of a Green America campaign to promote regenerative agriculture and cut food transportation costs.

→10% PORTION OF AGRICULTURE-RELATED GLOBAL HEATING CAUSED BY RICE CULTIVATION

Just Add Fish

_Rice has the biggest carbon footprint of any grain. Bite by bite, tiny minnows can make it much smaller.



BY Moises Velasquez-Manoff

ILLUSTRATION BY Violet Reed

NEXT TIME YOU SIT DOWN TO A BOWL OF steaming rice, consider this: Of all the grains humans eat, rice has the biggest carbon footprint. Of course, rice is a staple for half of humanity, which partly explains the outsize footprint. The big problem, though, is that rice is usually grown in water, and there's not much oxygen in the muddy bottom of a rice paddy. That low-oxygen muck is a happy place for a type of bacteria that produces methane. And each methane molecule can do far more harm to the climate than a carbon dioxide molecule, contributing nearly 30 times more warming over a 100-year span.

In other words, when you grow rice, you also grow a lot of climate-heating bacteria.

One potential solution: fish. Experiments by the nonprofit Resource Renewal Institute suggest that introducing fish to rice paddies kicks off a cascade of events that changes the water's bacterial communities and ends with less methane leaking into the atmosphere. The fix also offers up a different way of thinking about how living systems contribute to climate change.

If the project pans out, it could change rice cultivation around the world. So it's notable that the effort began almost accidentally. The organization started its Fish in the Fields project in 2012 to reduce overfishing in the wild. "It was going well," says Deborah Moskowitz, the institute's president. But in 2015, the outdoor-wear company Patagonia, a major funder of the institute, raised concerns about the climate impact of rice. The company asked Moskowitz if her group could do anything about the methane rising off the fields.

Moskowitz began to scour the scientific literature. She found evidence from Asia suggesting that fish grown in rice fields—an ancient practice in that region—could substantially reduce methane. But the findings weren't consistent, and no one could explain how fish pulled this off. So when Moskowitz came across a paper in the journal *Nature Communications* that investigated the fish-methane relationship in a different context—a lake—she was ecstatic.

For three summers, Shawn Devlin, the lead author of that paper, had divided a small Finnish lake in two with a curtain-like barrier. Because it was shallow and covered in ice every winter, the lake naturally lacked fish. Devlin introduced perch on one side and left the other side fish-free. Then, once a month, he measured the greenhouse gases coming off the lake. The side with fish produced 90 percent less methane than the side without.

How? The food chain. Aquatic ecosystems host a veritable Serengeti of microscopic organisms: Some microbes, like the problematic methane producers, grow fat on dead plant material. Others, however, eat methane. These methane lovers are known as methanotrophs.

When the perch showed up, they feasted on the methanotrophs' main predator, little creatures called zooplankton. With fewer zooplankton around, the methane-eating bacteria proliferated, capturing much of the lake's emissions before they could bubble into the atmosphere.

"It set me back on my heels," Moskowitz says of the paper. "I thought, 'Why should this lake be that much different from a flooded rice paddy?'"

Devlin, who's an ecologist at the University of Montana, didn't initially see how his findings might turn into a method for reducing emissions. He thought of the research as purely descriptive of certain lake dynamics. So when Moskowitz called him with her pitch to apply the idea to rice paddies, he was gobsmacked. "As an ecologist," Devlin told me, "to have the concept applied somewhere is such a rarity that it's mind-blowing." He headed to California.

The results of the collaboration so far have been promising. In California rice fields, golden shiner minnows introduced by the project have reduced methane coming off fallowed rice paddies by 64 percent. By trying different species and densities of fish, Devlin thinks he can get that number closer to the 90 percent he saw in Finland.

For Oswald Schmitz, an ecologist at the Yale School of Forestry and Environmental Studies (he's not involved in the project), the big lesson of Devlin's research is that "animal diversity drives the carbon cycle," he says. With a large predator present, carbon from decaying plant material gets shunted into fish meat instead of flowing into the atmosphere as methane. Animals might even be useful in conservation generally, helping ecosystems wilder than rice paddies sequester carbon and aiding in the fight against climate change. "We view animals as passengers on a sinking ship," Schmitz says, "when in fact, they're drivers of the ship."

On a wet, drizzly December day in California's Sacramento Valley, the Resource Renewal Institute launched its most ambitious test yet of this idea. Chance Cutrano, the organization's director of programs, emptied buckets of golden shiner minnows, their underbellies flashing silver, into a 7-acre paddy. Between 2,500 and 3,000 fish would enter the turbid water; later 13,000 more fish were plopped into two other locations. "This is as good as it gets for fish," Cutrano said. "Go forth and grow!"

For the rice farmers, Fish in the Fields offers the additional enticement of a second possible income stream from paddies that don't have much use in the winter. The paddies provide all the food the fish need, and the fish are harvested before rice planting season, so they don't interfere with the summer crop.

Where could farmers sell minnow protein? That winter day, Moskowitz had a proof of concept: pouches full of dried-fish dog treats. She'd baked them at home. "My kitchen smelled interesting after I made them," she told me with a smile. But her dog loved them.

MOISES VELASQUEZ-MANOFF *(@moisesvm) writes about health and science.*

Fungus: It's What's for Dinner

BY Adam Rogers

Meat is murder—of Earth's climate, at least. More than a quarter of the planet's ice-free land is inefficiently used for grazing, a third of all farmland grows food for animals, and livestock are prodigious belchers of greenhouse gases. Global demand for meat is spiking at exactly the moment it'd be really good for all of us to eat less of it.

Alas, meat is also freakin' delicious. High-tech plant-based replacements aspire to replicate its proteinaceous umami yumminess and texture, but pea-based Beyond and soy-based Impossible face technical challenges. So maybe it's time to look to a whole other kingdom of life for meaty not-meats: fungus.

Fast-growing meshworks of mycelial filaments can replicate meat's texture, and it'll eat pretty much any carbon source, including waste from various industrial processes. Decades ago, British-based Quorn was the beginning of this idea, but this year the number of startups planning to put fungus-based alternative proteins in stores and on plates is mushrooming.

PRIME ROOTS

FUNGUS: ASPERGILLUS ORYZAE

You've already eaten Berkeley, California–based Prime Roots' substrate. It's better known as koji, the fungus that gets the starches in rice and soy ready for fermentation into sake and soy sauce, producing all sorts of meaty flavors along the way. Prime Roots grows a particular variety of koji and adds fats and flavors for eatin'.

MEATI FOODS

FUNGUS: PROPRIETARY MYCELIAL STRAIN "ROSITA"

Boulder-based Meati pored through libraries of filamentous fungi used to make other stuff—citric acid, antibiotics—to find one that could grow directly in bioreactors. The resulting harvest is good enough to fry up in vegan butter and garlic all on its own.

SUSTAINABLE BIOPRODUCTS

FUNGUS: FUSARIUM SPP

Found in a Yellowstone hot spring, the fast-growing fungus that underpins Sustainable's products grows in open trays, no bioreactor required. Then it's just a matter of drying, pressing, and adding flavor.

→24% PORTION OF GLOBAL GREENHOUSE GAS EMISSIONS GENERATED BY AGRICULTURE AND FORESTRY

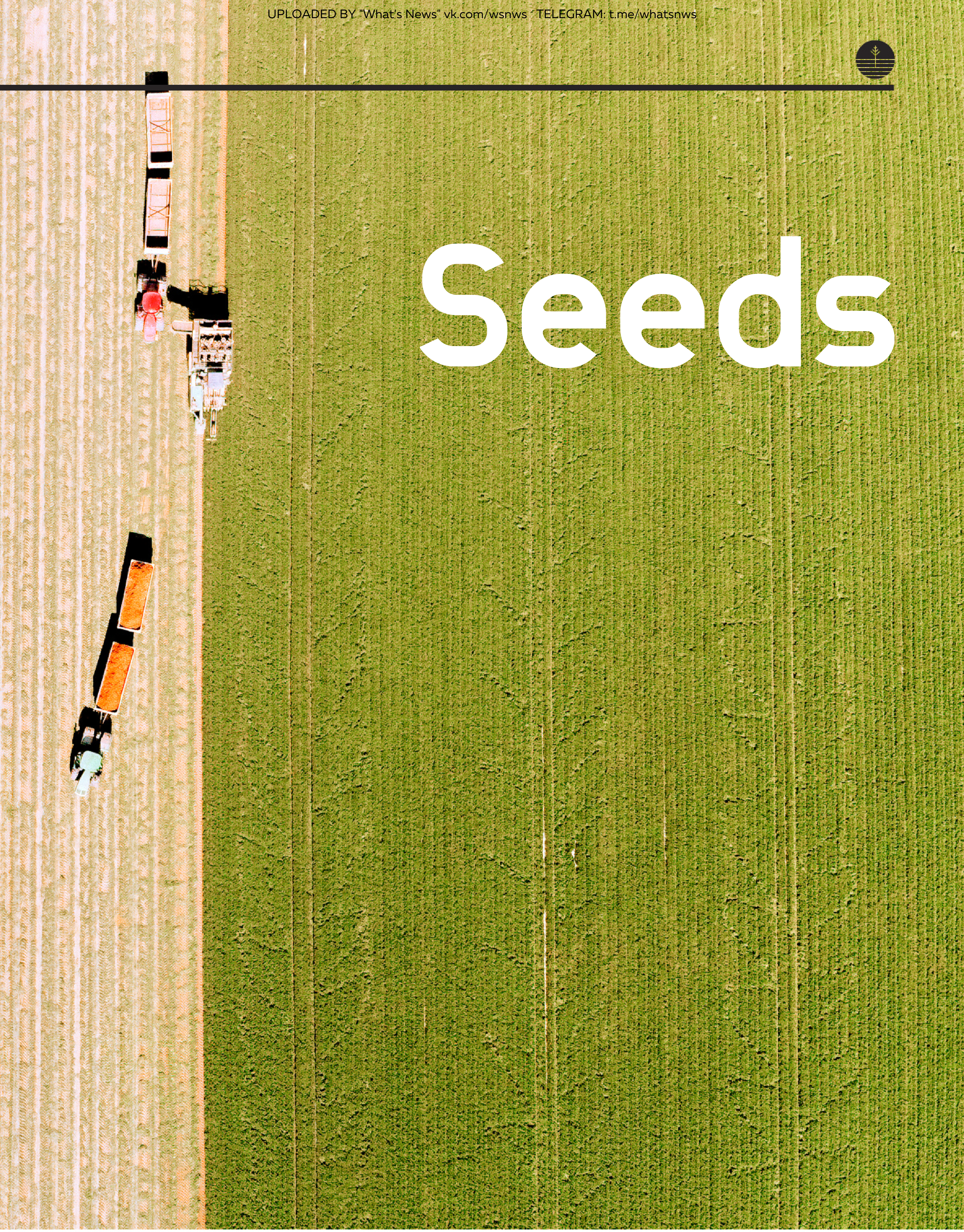
By Any

GMO. Organic. Hybrid. If we want to feed a growing population without feeding global warming, we need to redefine what we think of as good food.

BY Emma Marris PHOTOGRAPHS BY Cody Cobb

Necessary

Seeds



SOMEONE ONCE TOLD ME YOU COULD survive on just peanut butter sandwiches and oranges. I have no idea if that's true, but the advice suggested a tasty lunch for a road trip. It was a freezing, foggy day last December, and I was preparing to drive from my home in Klamath Falls, Oregon, to California's Central Valley, the great agricultural heartland of a state that produces a third of the country's vegetables and two-thirds of its fruits and nuts. As I spread my peanut butter, I read the packages on my counter. My nine-grain bread promised, vaguely, that it was "made with natural ingredients." My oranges were "locally grown." My peanut butter jar assured me twice, once on each side, that the spread was "NON GMO." It was even "CERTIFIED NON GMO." The inspection must have been a rather cursory affair, given that there are no genetically modified peanuts on the market.

The grocery aisle is a testament to our attachment to "natural" as a signifier for all that is good. And as many consumers become increasingly concerned about global warming, there's a tendency to assume that these same labels also mean a product is good for the planet.

But unfortunately, the packages on my counter and elsewhere in my kitchen, like my fancy organic sauerkraut ("Our passion for healthy, natural living is reflected in all our products"), told me very little that was relevant to climate change. My bag of local (that is, California) oranges presumably required less fossil fuel to get to my store than if they'd been from Mexico or Spain. But beyond that, I knew nothing.

Some labels—like "natural"—don't mean *anything*. A USDA organic certification is meaningful: It says the food was grown without certain forbidden synthetic chemicals and wasn't genetically modified. But the label in no way guarantees that the food was grown in a manner best for the climate. For one thing, many organic crops use more land than their conventional counterparts. When you clear land for crops, you often cut down forests—destroying a valuable carbon sink and turning it into a carbon leak. On the other hand, some conventional farming techniques use less land but rely on artificial fertilizer, which can make its way into the atmosphere as a potent greenhouse gas called nitrous oxide.

Which foods generate the fewest emissions? No federal certification will tell me that. And what's worse, even when consumers are presented with information relevant to climate change, they seem blind to it. One study suggested that, on average, "sustainability-conscious" American consumers will pay $1.16 more for a package of organic coffee, but they won't pay a premium for a less familiar "Carbon Footprint" label that quantifies the emissions associated with the product. This may simply reflect how 20 years of the organic label have conditioned public consciousness, but it also suggests something else: that our moral intuitions about food are out of whack with the demands of a crisis that is right on top of us.

This is a problem. Agriculture, including livestock and forestry, accounts for 24 percent of human-generated greenhouse gas emissions. We face a formidable challenge in the years ahead. We need to reduce those emissions and also sustain a growing population in a world of increasingly extreme conditions. And it would be nice if we could do it without expanding agriculture's footprint, so the rest of Earth's species can live here too.

To do so, we're going to need to abandon some of our attachment to what we perceive as natural, and not just at the supermarket. After all, we're not going to stop global warming merely by chasing after premium versions of food that only a few consumers can afford. We need to revise our thinking about food so that, as citizens, we can push for the regulatory policies that will meaningfully shift our entire food system's effect on the climate.

For my money, this system won't look like today's organic or today's conventional, but an evolving mix of both. As it happened, some important people—farmers and scientists—willing to cross these ideological lines lived not too far away. In looking around for people who are thinking deeply about climate change, I'd heard about Don Cameron, who farms a mere 7 hours and 45 minutes south of me. Hey, it's the West. That's practically a day trip.

SANDWICHES PACKED, COFFEE THERMOS filled, I kissed my two children and husband goodbye and headed south on US Route 97, out of the high desert basin where I live. Many hours later, as I approached Fresno, the landscape had flattened and dried out considerably. I'd eaten three sandwiches, several oranges, and finished my coffee. Early the next morning, after a night in a hotel, I drove through the darkness to Terranova Ranch. This farm, where Cameron is the general manager, sprawls over 6,000 acres in the already hot and dry San Joaquin Valley, an expanse that is expected to become 4 to 6 degrees warmer by the end of the century.

At the appointed hour, I showed up at the farm shop, where workers were gathering for the day, snacking on fresh almonds and joking in Spanish. Cameron, silver-haired in cowboy boots and fleece vest, suggested a tour of his operation in his Range Rover Sport. Terranova grows about 20 different crops. You may have munched on its pistachios; its red jalapeño peppers end up as Huy Fong's Sriracha sauce. The farm grows most of its food conventionally, but 950 acres are organic.

Driving by the fields, I was struck by how blurry the lines were between Terranova's organic and conventional operations. Cameron grows certain crops organically in part because they pay better, but he has also incorporated some organic techniques

_Plants are the staff of life. With help from scientists, they could also help cool a warming planet. A few examples at various stages of development:

1. The Land Institute is starting to commercialize a perennial wheat that doesn't require soil tilling, a process that releases carbon into the atmosphere.

into his conventional side because they work. Using chicken manure as fertilizer helped him add phosphate and potassium to his soil; owl boxes provide him with chemical-free gopher control.

Climate change is on Cameron's mind every day, he told me, because nearly every part of his operation is changing as a result. It was December, but splashes of red peppers missed by a recent harvest still lit up the fields. "We've been growing peppers late in the fall," he said. Ten years ago, they finished the harvest in September or October. "Falls are warm and springs are earlier."

Early hot days have begun to kill some of his tomatoes, and he's looking for new varieties that can take the heat. He worries about his pickers in midsummer. "We don't want them to get heat sick." One Fourth of July, Cameron picked peppers for a shift, taking over from an older woman who was feeling ill. "I picked for an hour; I thought I was going to die."

When I asked Cameron what new tools or technologies would help to cope with climate change, the very first thing he said was "drought resistance."

Worsening droughts are putting pressure on water in the valley. Groundwater levels are falling, and, to cope, Cameron has installed huge pumps, pipes, and channels to move water from the periodic floods on the Kings River onto his almond orchards and to recharge his aquifer. But what he really wants are crops that can thrive with less water, and he isn't too particular about whether they are bred the old-fashioned way or genetically modified.

In later winter many of the fields in the valley were expanses of bare, sandy earth; but along the edges were a few flourishing green shrubs, about knee-high. These were Russian thistles, better known as tumbleweeds. (Later, they will mature, detach, and roll away to disperse their seeds.) These plants, native to Eurasia, slipped into America with imported flax seed in 1873 and have thrived across the West. Cameron pointed to one of the bushes, emerald green without irrigation or tending. "That thing grows with no water," he said. "There's a gene out there that could really help us."

IN OTHER PARTS OF THE WARMING WORLD, drought is the least of farmers' worries: They struggle with too much water, not too little. Rice—the staple of more than half of humanity—grows in water, but it's finicky. While rice roots are happy underwater, the plant's leaves can't tolerate it. (Seedlings need to be transplanted into flooded paddies at the right point in maturity.) A flood that covers the whole plant will kill it.

In Davis, California, 190 miles from Terranova, I met up with Pamela Ronald, a plant geneticist at UC Davis who has worked to solve this problem. Climate change is making floods worse in parts of South Asia, and in 2006, Ronald helped create a kind of rice that can survive submersion in water. By 2017, some 6 million farmers in Bangladesh, Nepal, and India were growing this rice. We talked in her cozy office, where a painting hangs on the wall of a man under a deluge of rain struggling to plow a field.

The history of agriculture is all about human intervention, taking plants and breeding them to produce a better yield or tastier fruit. Ronald sped up this process by using molecular tools to identify the genes that allowed a low-yield rice to withstand floods. Colleagues at the International Rice Research Institute in the Philippines then bred the submergence-tolerant variety with popular high-yielding varieties. They used genetic markers to screen the resulting offspring when they were seedlings, keeping only those with the right genes.

This creation, Sub1 rice, is not considered a GMO by many definitions, because no genes from other species were inserted into the plants. But Ronald encourages genetically engineering crops if it can do anything to mitigate climate change or help low-income farmers. "You want all the options on the table for climate," she says. She points to a transgenic form of eggplant that is also a hit in Bangladesh. It contains a gene from a bacteria that allows the plant to repel a particularly destructive moth larvae, which is thriving in a hotter world. Farmers who plant this GMO eggplant variety are able to cease sometimes daily applications of toxic and expensive pesticides.

Affluent, environmentally conscious shoppers often shun GMOs, as any stroll down a Whole Foods aisle will attest. Organizations of organic farmers have generally fought to prevent GMOs from getting an organic label, even for traits like drought tolerance. Critiques generally fall into three camps: the often high cost of engineered seeds, concerns about herbicides sprayed on herbicide-resistant GMOs, and vague worries about safety. As far as the first criticism goes, it is true that some GMOs require farmers to

Reasons to Be (Somewhat) Hopeful

—

Food giants Unilever, Mars, Danone, and Nestlé say their US operations will continue to invest in farm conservation efforts and climate-friendly innovation, despite the Trump administration's decision to withdraw support for the Paris climate agreement.

—

The nonprofit GreenWave has helped 50 seaweed and shellfish farms go underwater. This "regenerative ocean farming" helps replenish marine ecosystems and provide food—and sequester carbon and nitrogen from the atmosphere.

—

New York City's public school system the nation's largest, with more than 1 million students—got a new cafeteria item last year: "Meatless Mondays."

2. Researchers at the Salk Institute want to encourage crop plants to grow roots that are rich in suberin, a substance that gloms onto carbon, and reach deeper into soil where the carbon can be stored.

3. Researchers at various universities are trying to figure out how to make cereals produce their own nitrogen, meaning no need for fertilizers and their emissions.

DON CAMERON, GENERAL MANAGER OF TERRANOVA, IN A FIELD OF CARROTS. HIS DREAM: DROUGHT-RESISTANT CROPS.

pay each year for expensive seeds, but that cost does not apply to crops developed by a nonprofit (as Sub1 rice was). The second applies only to the subset of GMOs that are engineered to tolerate glyphosate herbicide. (And to confuse things even more, some of the herbicides used before were arguably worse.) As far as safety goes, decades of scientific research has shown there's nothing especially different about genetically modified crops in terms of health or safety.

While most GMO crops are still either herbicide tolerant or pest resistant, more climate-change-ready traits are beginning to roll out. North American farmers are already planting corn engineered to be drought tolerant, though the seeds have mixed reviews. Genetically engineered drought-tolerant soybeans have been approved in the US, Brazil, Paraguay, and Argentina—where they are expected to be planted later this year. Corn engineered with drought tolerance and insect resistance for smallholder African farmers, funded by charitable entities, is aiming to be in farmers' hands by 2023.

With new, precise tools like Crispr gene editing, the potential is enormous. In addition to drought and heat tolerance, crops could be engineered to increase yields (and thus reduce agricultural footprints) and to be resistant to the pests and diseases that thrive in hotter climates.

The way Ronald sees it, we are in a crisis that demands every possible tool. Imagine that one of your loved ones had a virulent cancer, she says, and the most effective medicine was one that had been engineered in a lab. "You would never pull an option off the table because it was genetically engineered," she says. Why would we do so for our planet?

AFTER A SHORT WALK THROUGH THE UC Davis campus, I met up with Raoul Adamchak—bearded, bespectacled, and clad in overalls and a wide-brimmed hat. Since 1996, Adamchak has overseen the Market Garden at UC Davis. He cares for seven picture-perfect organic acres with a rotating crew of undergrads. The core of organic farming, he says, it to nourish soil with composts and manures, cover crops, and creative crop rotations rather than unhealthy or environmentally damaging chemicals.

As students washed purple carrots and sorted ruby-red beets, I helped Adamchak harvest a few rows of gai lan, a slender vegetable with yellow blooms. Organic farmers and geneticists tend to live in different ideological universes, and there's little trust between them. But Adamchak thinks GMOs should not be banned from the organic label. If Adamchak has managed to be more open-minded, it may be because he spends a significant amount of time talking to one particular crop scientist: Pam Ronald, his wife, with whom he wrote *Tomorrow's Table*, a plea for a detente between the sides.

The combination of GMO crops and organic farming methods, he says, could be particularly powerful for farmers on small plots in low-income countries. If staples like corn could be engineered to fix their own nitrogen, resist pests, and survive heat, cash-strapped farmers wouldn't have to buy inorganic fertilizer or pesticides. And they wouldn't starve as the climate warms.

GMOs aren't the only solution, of course, especially for many parts of the world that would benefit more quickly from solar-powered irrigation or other low-tech improvements. And the fact that many GMO seeds must be purchased anew every year is another drawback. Partly this is because they are almost always hybrids. Hybrids are plants whose parents are different varieties of the same species. They are beloved by farmers because of what is known as hybrid vigor: the nearly magical ability for the plant to produce more edible food than either parent variety while also being harder to kill.

Unfortunately, the offspring of hybrids are duds, producing unpredictable crops. Scientists have been working on that too. Another UC Davis plant geneticist, Imtiyaz Khanday, stumbled on a way to tweak a single gene and make hybrids breed true. Khanday's hybrids create seeds that are clones of themselves—preserving all the benefits of hybrid vigor and whatever drought, flood, or pest tolerance the hybrids were engineered to express. He hasn't mastered the technique yet, but his breakthrough could theoretically work in all sorts of crops. Farmers could save seeds and replant. He hopes to see the first hybrid clones in farmers' fields in 10 years, but concedes, "I am being very optimistic about it."

ON MY DRIVE BACK TO OREGON FROM DAVIS, I started imagining what agriculture could look like if it were optimized for climate. What if, instead of focusing on inputs like chemicals or genetically modified seeds, we threw out the old rules and started looking at outputs—like greenhouse gas emissions, land and water footprint, pollution, worker and consumer health and safety? The result might look like a mashup of organic and conventional, depending on the context and the crop. High yield, low emissions. And it might borrow heavily from a style of farming that's become a bit of a buzzword recently: regenerative agriculture.

The core concern in regenerative farming is storing more carbon in the soil. This has a double benefit: Carbon dioxide is pulled out of the atmosphere, and the stored carbon helps nourish the soil. Practically, this means that farmers try to keep the soil covered and undisturbed as much as possible. They reduce or eliminate tillage—plowing, harrowing, or otherwise churning up the soil. They use crops like clover to keep the ground covered and add nutrients when the fields are fallow. They use composts and manures, plant perennial crops rather than annuals, and incorporate charred vegetation residue into the soil. All these practices can change the ecosystem of the soil and its physical properties, making it better at holding moisture, nutrients, and carbon.

The number of acres in the US that are farmed without tilling increased from 96 million to 104 million between 2012 and 2017. During that same time, the amount of land planted with cover crops jumped from 10.2 million acres to 15.3 million acres. But consider this: There are 899 million acres of farmed land in the US. Farmers are a pragmatic bunch. If they are going to make changes, it has to pay. Back at home, I scheduled an interview with a startup called Indigo Ag, which has one nascent effort in that direction.

Based in Boston, with about $850 million in investment capital, Indigo pays farmers around $15 for every ton of carbon they add to their soil. Indigo claims that if every farmer boosted the proportion of their soil that is carbon to 3 percent (today's average is 1 percent), they could together draw down 1 trillion tons of CO_2—"the amount of carbon dioxide that has accumulated in the atmosphere since the beginning of the industrial revolution"—a figure that some soil experts say might be a bit aspirational.

Indigo also tries to connect farmers with buyers who appreciate more environmentally friendly practices. Corn, soy, rice, and cotton are typically sold as commodity crops at a standard price. Indigo Ag, however, runs a specialty marketplace where growers of crops who use sustainable practices—or grow grain to particular specifications—can sell their wares directly to food companies. "We think it is inevitable that our food system shifts to being decommoditized so farmers get paid not based on inputs or principles"—as in today's organic farming—"but on commitments to nutritional quality and environmental protection," says Geoffrey von Maltzahn, Indigo Ag's chief innovation officer. Anheuser-Busch is buying 2.2 million bushels of rice through Indigo, specifying that the grain must be made with 10 percent less water, 10 percent less nitrogen, and produce 10 percent less emissions than generic commodity rice—producing a Bud you can presumably quaff with 10 percent less guilt.

Getting enough farmers to store carbon will require more than a few virtue-signaling companies to pay a premium for their crops. Bigger forces have to come to bear. Indigo hopes governments will eventually incentivize farmers to store carbon—ideally setting a global price for every ton they are able to sock away, which von Maltzahn says would be "transformative to the economics of developing- and developed-world farmers."

Some policies already exist to encourage better agricultural practices. The US spends about $6 billion each year on programs that compensate farmers for environmental services like conserving topsoil or wildlife habitat. States run their own programs too. At Terranova, Don Cameron is tapping into one of these state programs to help pay for a 1.5-mile corridor of plants that support pollinators and insects that eat crop pests.

One can imagine a future where "farmers" spend just as much time and make as much money storing carbon and maintaining clean water and wildlife as they do selling soybeans and carrots. Farmers in such a system could become a real climate-mitigation force. Consumers would have a slew of new labels to choose from beyond organic: regenerative, carbon negative, wildlife friendly, and so on. In the best of all possible futures, one can imagine that these approaches become so mainstream that the labels simply disappear, because incentives and regulations ensure that all agriculture is producing safe, healthy food while simultaneously improving the environment.

In a system judged by outputs, not inputs, farmers could mix gene editing and automation with cover crops and compost and monarch butterflies and owls. They could create their own kind of hybrid vigor.

Planning the future of the food system made me hungry. When I got home, I chopped up some conventional orange carrots that Cameron had yanked out of the ground for me at Terranova and some of Adamchak's organic purple and white carrots and mixed them together. I drizzled them in olive oil from California groves, seasoned them with salt and pepper, and roasted them in the oven. My kids couldn't get enough.

EMMA MARRIS *(@emma_marris) writes about the environment and wild things.*

→62% PORTION OF GLOBAL AGRICULTURE EMISSIONS GENERATED BY CATTLE

Meatspace

_Implementing radical climate solutions is less a technological project than an anthropological one.

BY Virginia Heffernan

ILLUSTRATION BY Alvaro Dominguez

PAT BROWN, THE STANFORD BIOCHEMIST who founded Impossible Foods, was trying to be patient, as if he were addressing a dim sophomore. This was five years ago, and his company's signature product—a bona fide burger made from plants and animated by a molecule from soy plants that's bio-equivalent to mammal blood—hadn't yet found its way to Burger King and White Castle. I'd come to his office in Redwood City, California, to talk to him about whether consumers really would start eating a beef simulacrum.

Now *this* was a startup. In identifying heme, that blood-like molecule, Brown had a galvanizing innovation. And his company had a crystal-clear reason for being: to meaningfully reduce livestock farming, the industry that produces 14.5 percent of all greenhouse gas emissions. Yet Brown seemed to invert the priorities of other CEOs. He was a reticent marketer and eschewed the founder showbiz routine, which sometimes seems to represent the whole enchilada at other startups.

But Impossible was going to need finesse. People are very weird about meat. I had a question I considered urgent: "What do you think consumers, who are panicked about GMOs, will make of the genetic modification required to transform plants into meat?"

There was silence. Brown didn't quite say *mmkay*, but he looked weary, so weary, as if I'd asked him about the opinions of flatearthers and chupacabra hunters.

Brown, who is a vegan, seemed to find the peculiar human folkways involving meat enervating. He pointed me to a study by Oklahoma State University that showed that 82 percent of Americans said they'd support "mandatory labels on foods containing DNA."

I let that sink in. What's edible that's free of DNA? I wondered. Maybe salt. Maybe Starbursts. "Does that leave gravel?" I asked.

"Ordinary consumers don't know very much about genetic material," he said, dryly.

True. Likewise, it seems, we don't know much about Crispr, nuclear power, or geoengineering. No wonder it's hell marketing big solutions for the climate crisis to us; many of us think DNA in food is cause for alarm. Then we worry about the destruction of DNA by nuclear waste, though an expanded nuclear program is a way to prolong the life of the planet. Like superstitious yokels from the dawn of time, we just know what we like and what we don't. And we don't like things that sound … hinky or creepy. Or, worse, things that sound like something someone who's not in our tribe might be excited about.

This is why implementing the next phase of radical climate solutions is less a technological project than an anthropological one. The field of anthropology, which thrived in the last century, has deteriorated in recent years; this is a loss. Franz Boas, who is considered the father of American cultural anthropology, devised the field in part to counter the sophistry of scientific racism. Anthropologists who followed him (including his students Zora Neale Hurston and Margaret Mead) continued in this liberal tradition, focusing on how people come by superstitions—including, in the West, "scientific racism"—the better to recognize, and correct for, their own.

Ventures devoted to reducing livestock farming, including Impossible Foods, could use these minds and methodologies now. Dietary laws around the globe exist chiefly to express anxiety about meat. There are vegetarian religions like Jainism; tribes like the Maasai, who largely reject the meat of wild animals in favor of the blood and milk of cows; Muslim and Jewish adherents to the laws of halal or kashrut; and many modern cultures that eat meat with such relish that they aim bitter resentment at anyone who would curb their zeal. "Everyone calls what is not their own custom barbarism," as Montaigne put it.

A seminal book from the heyday of anthropology touches explicitly on meat, flesh, and irrationality: *The Raw and the Cooked* (1964). Author Claude Lévi-Strauss investigated how cultures structure experience around contrived binary oppositions. The raw and the cooked is a tenacious one. Think about foodies' obsession with the preparation of meat. Where cooked meat—fire, ovens, stoves—would seem to be more adaptive than raw, it's meat prepared closer to raw that represents haute cuisine in the West, and the temperature one prefers for meat is a vital class signifier. To order meat well done might be to lose status in Paris; elsewhere, to order it raw, as steak tartare, might be deadly.

Anyone working to address climate change should be mindful of the anthropological notion of taboos. To scientists, the idea of ginning up a super race of mice or suffusing Earth's atmosphere with aerosolized mirrors might seem promising; to many of the rest of us, these ideas trip bad wires. Most of the wildest, reverse-the-polarities ways that figures like Brown have proposed to forestall catastrophe tread on sensitive spots in the brain: flinch reflexes, squeamishness, areas of dizzying ignorance.

Kirsty Gogan, who advocates for expanding the use of nuclear power at Energy for Humanity, her NGO, has even identified gut revulsion from solutions perceived as taboos as a *culprit* in the climate crisis. In tandem, Herbert Lin, a senior research scholar for cyber policy and security at Stanford, believes the planet is imperiled in part because we're starting to leave a shared idea of reason behind and retreating into what Lin describes as "fantasy and rage." To claim to be "paleo" or "anti-vax" is less to make an observation about reality and more to claim a personal and tribal affiliation, grounded in fantasy and rage, totem and taboo.

All of the most promising routes to decarbonization, every last one of them, require that humans change beliefs and behaviors with which they may identify. The modern imperative, if humans and our habitat are to survive, is to interrogate cultural idées fixes—about food, freedom, tribal identity, the body, water, even evidence and truth. Marketing, while useful for promoting coziness and self-indulgence, is crap at getting people to question their cherished beliefs.

Because of the force of human superstitions, more mighty than petroleum and more central to our survival than the internet, Gogan has also written, "All of our climate solutions must be impossible burgers."

She means we need to think like Brown, whose research ultimately showed him that most fast-food consumers don't think about the origin of their burgers, or the halo of eating plants, or even about health value. They care about taste, price, familiarity, and—to a lesser extent—novelty. Impossible and its rival, Beyond Meat, nailed these qualities, and neither bothered to hold symposia on DNA; lessons in biochemistry tend to kill the burger buzz—the highly ritualized consumption of cheap protein, generally in a colorful and sociable setting. Like Burger King. Last year, the sale of plant-based burgers went up 10 percent. Most importantly, the meat-from-plants was bought and consumed in richly appointed tribal settings that give comfort: Applebee's, Hardee's, TGI Fridays, Hard Rock Café, and Dunkin'.

Brown's burger has won over consumers, in other words, without setting off alarms about altering DNA or eliminating cattle ranches. These days, Impossible's site doesn't mince words: "Genetic engineering is an essential part of our mission and our product. We've always embraced the responsible, constructive use of genetic engineering to solve critical environmental, health, safety, and food security problems." In five years, the stigma on GMOs has lifted; roving panic about DNA moved on. Now that fake meat is everywhere and scientists have extolled its adoption, people tabled the GMO question, much the way we tabled "test tube baby" concerns when IVF became commonplace.

As a common noun, *impossible burger* may come to mean the thing that human systems of thought and practice would never accommodate—until they did. For her part, Gogan, in her quest to spread nuclear power against quasi-religious objections from all quarters, has closely tracked Brown's audacity and success in introducing his burgers on a large scale—and, more astonishing still, getting the GMO- and even DNA-shy to relish them. This is the way the planet is saved.

VIRGINIA HEFFERNAN *(@page88) is a regular contributor to* WIRED.

“Want to cut carbon? Get people to drive less. But to do it, we’ll need different kinds of cities.” page 58

Move

HOW WE’LL DRIVE (AND FLY AND RIDE, OR STAY PUT) BETTER

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→70% PORTION OF GLOBAL GREENHOUSE GAS EMISSIONS ATTRIBUTABLE TO CITIES

Road Warrior

_Across the globe, cities are remaking their streets for bikes, buses, and feet—not cars. For Jeff Tumlin, the new head of San Francisco's transit agency, that's essential. It's good for business, good for people, and amazing for the planet.

BY Adam Rogers

PHOTOGRAPHS BY Cayce Clifford


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FOR 30 YEARS, A 40-FOOT-HIGH SECTION of US Route 101 wove like a blackberry vine through a low, old neighborhood of Edwardian and Georgian buildings in San Francisco's Hayes Valley. Then, in 1989, the Loma Prieta earthquake, magnitude 6.9, fractured the elevated roadway. Some people wanted to repair it, but the city decided to tear it down—a rare unbuilding in a nation connected by highways.

Today it's hard to imagine that anyone defended the spur. The highway formed a wall between neighborhoods, and the right-of-way beneath it was a dark, unloved space. With the freeway pruned away, the city styled the newly revealed surface street—Octavia—after a grand Parisian boulevard, with an inner couple of lanes separated from parallel side streets by tree-lined islands. Octavia now terminates in a long, grassy park with a geodesic children's play structure at one end. Nearby are pricey shops and chic cafés.

Back when Jeff Tumlin was on staff at the urban planning consultancy Nelson\Nygaard, he worked on this remaking of Octavia Street and Hayes Valley. Now Tumlin—tall, lean, and bearded—is the new head of San Francisco's Municipal Transportation Agency. On a sunny winter morning, he and I head for that green space so he can show me the freeway's ghost, barely visible in the odd, polygonal footprints of newer buildings along Hayes Street—they're catawampus, tucked into the spaces where the concrete artery used to curve through, insensible to the city's grid. Take away the veil of freeway and you get space for a more boogie-woogie street fabric. Less freeway, more park.

Tumlin has a preternatural awareness of urban ectoplasm. He's going to need it. Like the Loma Prieta quake, Tumlin is about to shake some things until they break—carve up a few more roads to create bike paths, new busways, parks ... whole new ways for people to move around. It won't be easy; lefty, crazy San Francisco becomes the most conservative city in the country when it comes to changing the look and feel of the place. But this is the revolution that Tumlin and a generation of new-wave planners are waging.

"Almost no matter what you want to do with cities, transportation is the fastest and most cost-effective way of achieving your goals," he says. "If you want to reduce CO_2 emissions, if you want to advance social equity, if you want to foster small business success, if you want to increase land value, if you want to increase public health, if you want to reduce fatalities and injuries—transport is the place to do it."

CARS ARE GREAT. I SAY THAT AS AN Angeleno who grew up thinking of them as a perfect amalgam of fashion signifier and Gundam mech-armor, but also because of everything that the private automobile has made possible. Vanguard of an economic boom, the car democratized freedom of movement and social privacy—privileges that had been available only to wealthy white men. The whole economic premise of Fordism was that the laborers who powered the late industrial revolution, who built the cars, should also be able to afford them. And wow, did that ever happen. When the assembly lines spun up at the beginning of the 20th century, Americans owned just a few thousand cars. By the end of World War II, it was 30 million. As of 2017, there were more than 193 million cars and light-duty trucks in the US. That's roughly three cars for every four adults.

Cars are also terrible. They kill about 40,000 people every year in the US and injure millions more. Americans spend 54 hours per year slowly losing their minds in traffic, a waste of $179 billion in lost productivity and 3.3 billion gallons of gas. Transportation accounts for nearly a third of total greenhouse gas emissions in the US, and more than half of that is from cars. Combustion engines simply cannot help emitting carbon-based molecules that violently deconstruct Earth's climate. Cars—especially the short-hop, sub-5-mile trips that people who live in cities take as a matter of both habit and necessity—are the most obvious cause of climate change.

Or: You. It's you, driving to work, picking up kids, driving to the movies, doing the shopping. Your car habit is killing the world with fire and flood.

Really, though, it's not you. It's *them*—the people who made the laws that shaped the urban world and the people who built cities to fit them. Driving seems like what an economist would call a revealed preference, a thing people obviously love because they do it so much. But it's not. Driving is an *enforced* preference. The modern American city is designed to favor cars and make other ways of getting around suck. That's been true for at least six decades, but today our limited ability to imagine different shapes for cities is causing environmental collapse. It's time to hit the brakes. Want to cut carbon? Get people to drive less. But to do it, we'll need different kinds of cities.

TUMLIN HAS A DEGREE IN URBAN STUDIES from Stanford, which didn't help him get a job when he graduated in 1991 and moved to San Francisco. He was poor, but that was OK. "I was having my perfect young, queer, new San Francisco arrival experience. Those were my formative years. I was finally having a life."

So when Tumlin finally got an offer a year or so later, it held little appeal. It was back at Stanford, running the unglamorous university parking system. Except, dollars. "I thought, OK, fine, I will do this, ignore my

_The state of California stopped buying (most) solely gas-powered vehicles for its fleets at the end of 2019—all part of the governor's efforts to reduce greenhouse emissions in the state.

job description, and they will fire me. But I'll make enough money to go to graduate school," he says.

He arrived back on campus amid a crisis. The earthquake that knocked over the San Francisco freeway had also damaged about a third of the university's buildings. Its considerable endowment was down too. Stanford's land had become its most valuable resource.

Taking advantage of that resource, though, was a whole other thing. Constant not-in-my-backyardist opposition to Stanford's real estate development efforts had culminated in what Tumlin describes as a "bizarre deal" with Santa Clara County, where the campus sits. It was an omnibus, but with a catch: The school was allowed to develop up to 2.1 million square feet of new construction—but only if peak-period traffic around the campus stayed at 1989 levels.

That seemed impossible. More buildings would necessarily mean more people, which would necessarily mean more cars, right? And all of them would want to sit on what Tumlin increasingly thought of as his parking lots, so he'd have to build more of those too … which would induce demand for more cars and cause more traffic. But then his team came up with a radical plan. "What's unique about universities is that they are the property owner, the developer, the landlord, and the tenant," Tumlin says. "They can actually do systems thinking in a way that is rarely possible for government agencies, particularly transit agencies." Tumlin, the head of parking, decided not to build any more parking lots.

Instead, his department offered every Stanford employee $90 a year, cash, if they didn't buy a parking permit while simultaneously raising parking rates. Rather than spend $18 million building new lots, Stanford spent $4 million of the parking income on paths and places to lock up bikes, banned private cars from a main road on campus—buses and bikes still allowed—and built 2.1 million square feet of buildings. Traffic remained at its 1989 baseline.

While it's true that universities are more terrarium than town, the tension between using land for cars or for people—whether to build infrastructure for private journeys or public destinations, if you will—stymies cities too. How do you make sure people can easily get to where they want to go? Public transit networks, mostly rail, guided the growth of US cities through the first half of the 20th century. Even the booming metropolises of the postwar years—Los Angeles most famously—sprawled along the branches of metastatic trolley networks. Then a methodical automotive-industry public relations project taught Americans that the freedom of movement cars offered wasn't just convenient, it was downright patriotic—much more so than dirty, crowded cities. Carmakers lobbied for road-building—like, how about a whole interstate highway system?—and road builders came to support anything that led people to buy a new car. Cities across the US tore the tracks up. You can see their ghosts in the broad grassy median strips on boulevards across the country.

Racism and classism go a long way toward explaining why public transit got nuked, but that nuking is still a weird, self-hating move. It makes cities a lot less fun. Researchers disagree about the degree to which people love big houses on curvy cul-de-sacs and malls anchored by big-box stores versus, say, multiunit housing, densely packed skyscrapers with street-level retail, and a vibrant café culture. But let's just stipulate that people who like cities like cities.

Yet those preferences aren't reflected in the classic guidelines for traffic planning. The standards simply favor plenty of parking and streets that hold a lot of cars. The result is sprawl, downtowns that empty at 6 pm, car-dependent suburbs and exurbs, and roads choked with traffic. This kind of city—Houston, Phoenix, greater Los Angeles—eats up resources and coughs out carbon. It's obvious when you say it out loud, right? Cities take up 2 percent of all land on Earth, but they're responsible for 70 percent of global emissions. But in dense cities with transit, people drive less. "Right now, cars are the dominant life-form in most of our cities," says Daniel Kammen, an energy researcher at UC Berkeley, "not people."

European cities have been doing radical surgery on themselves to cure those ills for decades. But one of the first people in the US to try to put that knowledge to work was the head of New York City's Department of Transportation, a San Francisco–born New Yorker named Janette Sadik-Khan. Appointed by Mayor Michael Bloomberg in 2007, Sadik-Khan had already been a federal transportation official and worked for New York under Mayor David Dinkins. The year she started her new job, New York

What You Can Do

LEVEL 1

PRIME AND CHILL

Ordered today, arriving tomorrow: a single pair of socks in a giant cardboard box. Cut down on emissions and waste by ordering big and shipping slow.

LEVEL 2

LEG UP

If we have to travel more than a quarter of a mile, most of us drive. Extend your walking range to a full mile or two, getting your steps up and your carbon footprint down.

LEVEL 3

BECOME A TRANSIT EVANGELIST

Plan a car-free day in your neighborhood, write letters to the editor, and campaign for local pro-transit candidates—or run for office yourself.

_In January, California stopped buying fleet vehicles from GM, Toyota, Fiat, and Chrysler, after they sided with the Trump administration's refusal to let the state set stricter fuel economy standards of 51 mpg on average by 2026. Ford, VW, BMW, and Honda have signed on to the new rules.

was looking at a million more people moving in by 2030, but the administration also wanted to reduce emissions. Sadik-Khan came home from a trip to bicycle-crazy Copenhagen with an idea: Move parallel-parked cars a few feet out from the curb and use them as a bulwark for bike lanes. "We'd sort of lost the script that our streets could be for anyone else," Sadik-Khan says. "People that were walking or biking or taking transit, they were left with a scrap of the street." So she took some of it back.

New York drivers, never shy, complained about losing lanes. Retailers worried about losing customers. But polling showed that pretty much everyone else loved Sadik-Khan's changes. She got 400 miles of bikeways built. She turned Times Square car-free, started a bike-share program, and helped found a national organization of city planners that could teach US cities to push these kinds of ideas as hard as the old car-forward ones. "We just lit the spark, gave cities permission to innovate," Sadik-Khan says. "Change is difficult. A lot of cities are debating whether to build more roads and highways. They need to stop repeating the failures of the last century."

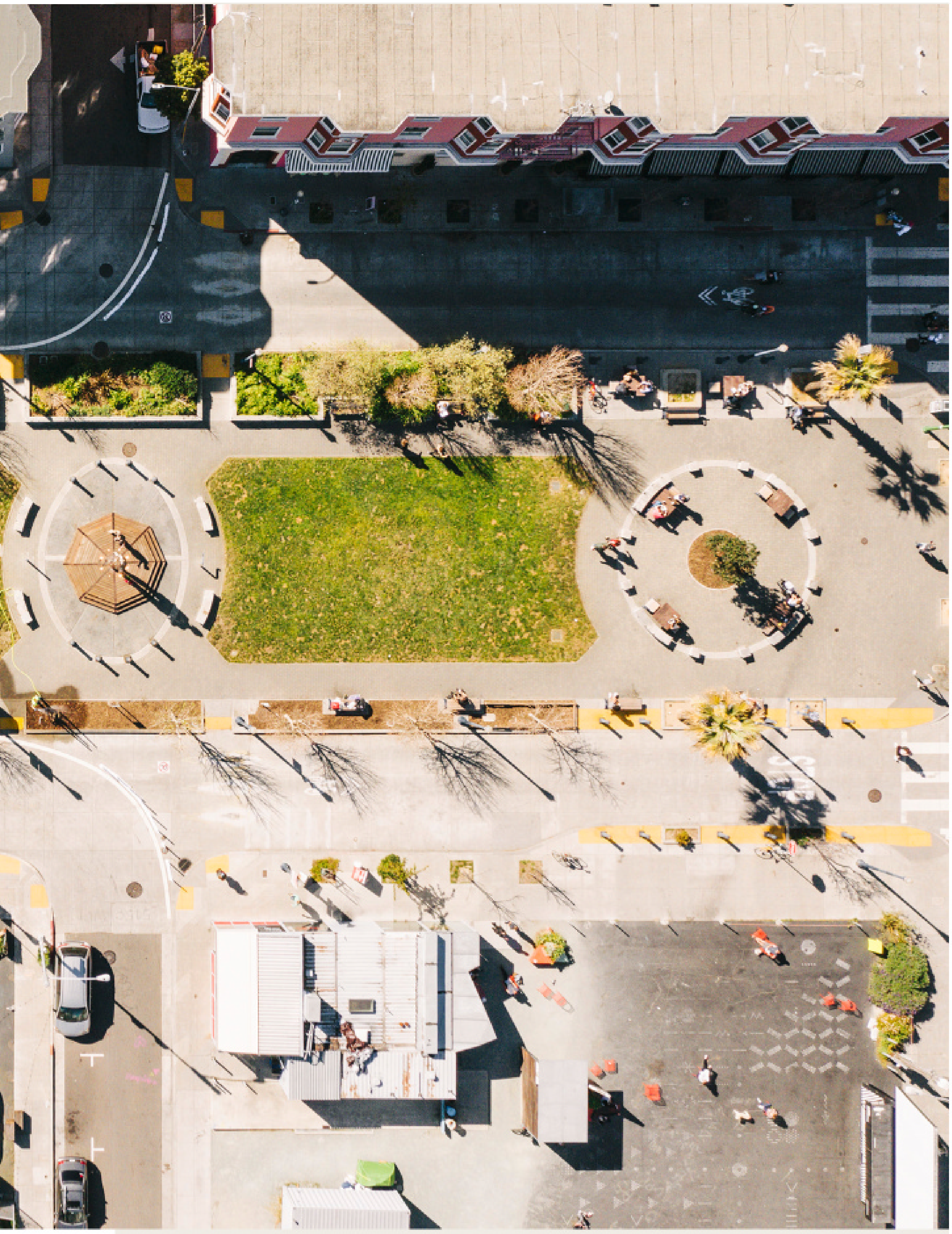
TUMLIN EXPERTLY PEDALS A BRIGHT orange Jump bike toward the park on Octavia. I'm less expertly pedaling his bike, an electrically boosted thing that'll spin up to 25 mph if I don't watch it. (Tumlin often tweets about his rides on his ebike, and a few weeks after our trip, someone tried to steal it—during Tumlin's photo shoot for WIRED. He ran after the guy and got it back.)

Honestly, I look like a wobbly, bike-curious dope in a secondhand helmet. Tumlin, on the other hand, cuts a natty figure in a sweater, jacket, and really nice shoes. (At work he favors tailored suits; a local news outlet reported his new job with the headline "Mayor Appoints Stone Cold Fox Jeffrey Tumlin to Lead SFMTA.")

The Parisian version of Octavia, it turns out, isn't all he'd hoped. "We screwed this one up," Tumlin says. "The island is too narrow, so the outside lanes are too wide." Traffic pours off the still extant part of the old freeway toward the park, and some cars use the outside lanes to bypass the center. Making the point, a silver sedan rolls up and presses us from behind. We float right and it accelerates. I see Uber and Lyft stickers in its rear window. As the sedan crawls past, Tumlin looks through the window at the driver, smiles broadly, locks the extended middle finger of his left hand on target, and says, amiably but loud: "Fuuuuuck yoooooou."

Maybe that makes Tumlin sound like a zealot or an asshole. In my time with him, he was neither; he says he just doesn't like bullies. And he thinks that cars screw up cities. That's why he peels off from the park and turns down a side street. A hundred years ago it would have been an alley; a hundred years before that it might've been space for horse-drawn carriages. Now it's a cozy street full of shops—an expensive luggage store with displays more like an art gallery, a famous maker of custom-made corsetry. We dismount where the street is lined with stone benches and plantings that make it almost too narrow for cars. That's what Tumlin wants to show me. This urbane little street is designed for people moving at the speed our eyes and brains are most able to process and respond to, he says—which happens to be no faster than a run. But behind the wheel of a car, inputs come too fast. Thirty miles an hour! Locked in a steel box, toggling between a crime podcast and Google Maps, an illusion of aloneness

Drone operator: Noah Berger



disconnects us from the sometimes literal impacts of our behavior. We get, frankly, deranged. "The social contract breaks down," Tumlin says.

"Yeah," I say. "You don't even have to wear pants in a car."

"It's also literally the only place you can get away with murdering someone by calling it an accident," he says.

The people sharing spaces on the sidewalk, or inside a bus or subway car, though, self-assemble as if in a theater where we perform civil society for each other. We remove our backpacks so more people can fit. We let people exit before we enter. Someone in front of us drops something, we

OCTAVIA STREET, IN HAYES VALLEY, WAS COMPLETELY REMADE WITH PARKS AND PEOPLE IN MIND AFTER THE 1989 LOMA PRIETA EARTHQUAKE USHERED THE FREEWAY OUT.

Street Sweepers

BY Adam Rogers

Cars emit a huge chunk of cities' greenhouse gases, but cities are doing something about it—and not just in New York, Paris, and San Francisco. It makes sense: Cities that don't help destroy the planet are also nice places to live.

CITY: SEOUL

METHOD: UNBUILDING

In 2003, Seoul shifted a freeway-building binge into reverse. City workers dismantled an expressway and turned its path into a popular park. Since then, Seoul has knocked down 15 more freeways and is building a transit network emphasizing bikes and trolleys.

CITY: BARCELONA

METHOD: SUPERBLOCKS

The city's basic plan was already a grid of wide boulevards threaded with smaller side streets. Barcelona made side streets narrower, greener, and more parklike—extremely unfriendly to cars, which now stick to the perimeters. These new superblocks are so popular, the city plans to make 500 more.

CITY: COPENHAGEN

METHOD: BIKES, BIKES, BIKES

Copenhagen was as car-choked as any modern city. But years ago, moms and urban planners united to make streets safer for children by encouraging bikes and walking. Today the city has more than 250 miles of bike lanes, including bike-only bridges and cycle superhighways. Almost two-thirds of the city's 1.3 million residents bike to work or school.

CITY: LOS ANGELES

METHOD: BUSES

The city most famous for car culture is doubling down on public transportation. In the face of nationwide declines in bus ridership, LA's Metro is using survey data, community meetings, and location-based cell phone tracking to make buses faster and easier to reach for 2.2 million people.

CITY: TEMPE, ARIZONA

METHOD: HOUSING WITHOUT CARS

Amid the sprawl of greater Phoenix, a development called Culdesac—opening this year—has 16 acres of housing, enough for 1,000 people, built next to a light rail line, and no residential parking. Cars aren't allowed.

pick it up for them. Tumlin has shown me this little street because it's scaled to let all that happen. "But I can't say my job is telling people about civility," he says.

After he left Stanford and ended up at Nelson\Nygaard, Tumlin worked not only on that Octavia park but in cities from Seattle to Abu Dhabi. In fact, a lot of what he's planning for San Francisco would look familiar to the rest of the world. New York just closed 14th Street, a key crosstown boulevard, to private cars—a bus trip that took 17 minutes now takes just 10, and weekday ridership has been up 17 percent. Seattle's adding new homes and new transit. Oslo is banning cars from its city center. The center of Ghent in Belgium is divided into zones that transit can cross freely but cars can't. London charges drivers to enter downtown. And Paris—oh, man, Paris. After building miles of bike lanes and turning huge swaths of the city car-free, Mayor Anne Hidalgo has reduced car traffic by 22 percent. Her reelection campaign is predicated on eliminating 60,000 parking spaces and building a "city of 15 minutes," where jobs, housing, and anything great is within a quarter-hour's trip—on foot, on bike, or on Metro.

That's all a ways off for San Francisco, but you can see the road ahead. As Tumlin and I pedal over to the long north-south artery of Van Ness Avenue, we have to dismount to get past a construction project, where workers are putting in separate lanes for bikes and buses. We hang a left on Market Street and pull into the new bike lanes tucked behind new boarding islands for buses, all built in preparation for Market's closure to private automotive traffic. (A proposal to set aside part of the San Francisco–to–Oakland Bay Bridge for buses is pending.)

Of course there are obstacles. At one point on our ride, the bike lane we're following takes a sudden turn away from the curb, out into traffic, and then quickly back inward again. Thanks to the litigious, whiny owner of the store we have just passed, the bike lane zigzags around exactly one car's worth of parking. And, acceding to local demand, the transit agency built a handful of the city's new trolley-boarding platforms with a single parking space, positioned so that a car in that spot blocks the doors of an entire trolley car. "While at the citywide level, I think we could all agree that the safety of transit riders is more important than a single parking space," Tumlin says wryly, "at the block level, it becomes more challenging."

> "For a lot of people a car means freedom and social status. But if a city provides you no choice but to drive, a car isn't freedom, it's dependence."

THE MISSION BAY NEIGHBORHOOD, SOUTH of the Giants' baseball stadium, used to be wetland, industrial buildings, and parking lots. Now Tumlin and I ride through a gleaming new town, built higher and denser than most of the city, threaded through with a burgeoning UC San Francisco campus. At a park that has become a semipermanent cluster of food trucks, Tumlin and I lock up the bikes and get food. Surrounded by med school students nursing brunch cocktails, we talk about a special irony of his new job. Everything he's trying to do is the philosophical opposite of the plans a bunch of powerful technology companies just a few miles away have for disrupting cars.

Their solutions sound pretty good at first. Electric cars don't emit carbon—at least not locally. Robot cars are supposed to be smart enough, someday, to platoon together as close as the segments of a caterpillar, solving traffic congestion. And when we don't need them they'll just sort of float away instead of requiring giant parking structures. Imagine Uber, but without the oppression of the proletariat.

Tumlin doesn't buy any of it. New car technologies don't solve old car problems. Models of a city where only robot Ubers ply the roads hint at smoother traffic flow, but a more realistic simulation—one combining dumb private cars driven by dumb people (not you, other people)—showed increased congestion and more pollution. Ride-hail services already simulate what a robot autopia would look like, and it turns out for solo trips they emit about 50 per-

_In Portland, bike lanes with barriers that protect them from traffic have helped reduce road fatalities for cyclists, pedestrians, and motorists by 75 percent over 20 years—even as the number of cyclists quintupled.

_If an automaker shaves 10 percent off the weight of a vehicle, it can increase the vehicle's fuel economy by up to 8 percent.

cent more carbon dioxide than private cars per passenger-mile. Half the time those cars are on the road they're roving, empty, trawling for fares.

If you're hoping that electric cars will solve that carbon problem, well, maybe. But electrics are a stable 2 percent of the US fleet; SUVs are 70 percent and climbing. It's not enough to make a dent. "There's this incredibly tech-centric discussion around fuel sources that misses the many ways that cars pollute," says Jeff Speck, author of *Walkable City: How Downtown Can Save America, One Step at a Time*. "Even if they swarm, they're about 1/500th as spatially efficient as a train, and in cities, space is capital."

If a city's most valuable resource is its land, the idea should be to let more people make use of it, not fewer people with more expensive toys. "Congestion is an economic problem, not an infrastructure one," Tumlin says. Streets are a resource, often poorly managed. Transit serves more people more efficiently. That's the real problem with Ubers and Lyfts, in the end. "Left to their own devices, private mobility operators will provide more exquisite personal convenience for the privileged," he says. "The result of Uber and Lyft is that my streets can move fewer people."

"For a lot of people a car means freedom and social status," says Janette Sadik-Khan. "But if a city provides you no choice but to drive, a car isn't freedom, it's dependence. If you have no choice but to drive for every trip, it's not your fault. Your city has failed."

THIS IS TUMLIN'S HONEYMOON PHASE. He's still a little famous for dressing, one Halloween, as the city's new marquee bus terminal, with a tessellated white metal skin and, famously, a broken spar that required an eight-month closure for repair. He printed out the Penrose pattern for his suit and wore a top hat with a crack. Tumlin's social media presence is so cheeky, people @reply him to complain when buses are late. The mayor and Board of Supervisors support him.

But the city's public works department is embroiled in a corruption scandal that could expand, and Tumlin's agency is groaning under the weight of bad morale and hundreds of unfilled jobs. Some of his jobs problem is just city bureaucracy BS. But another is also an issue nationwide: housing. Being a bus operator has, historically, been the kind of job that provides a pathway to the middle class in the US, especially for people of color. Yet someone who can't afford to live in the Bay Area can't get that job. "The rising cost of housing outpaces an employer's ability to pay," Tumlin says. "I am talking out loud about converting office space to dormitories."

At about the same time as American cities started pulling up their trolley tracks, they were passing laws that made it harder to build dense housing. Governments started encouraging people to own their own houses on their own plots of land, and weird baby boomer pastoralism and racism produced exclusionary zoning laws.

The result? Small businesses can't thrive. Gentrification displaces poorer residents. Homelessness goes up. The construction of new homes gets pushed to the edges of cities and beyond, so people have to drive more, which makes their lives more expensive and emits more greenhouse gases. Transportation and housing are as intertwined as strands of DNA. But in California, legislation that would have made it easier to build clustered, multiunit housing near transit lines has failed to pass the state's Senate two years in a row. If you make it illegal to build dense cities, it's hard to cut carbon. "Housing policy is climate policy," says Constantine Samaras, a climate and energy researcher at Carnegie Mellon University. "City policy is climate policy."

A lot of home-owning Americans find local produce shops and neighborhood cafés in front of apartment buildings charming as hell in Paris or Tokyo, but they'll take to the city-council barricades to prevent their construction back home—in defense of "parking" or "neighborhood character." That's especially true in San Francisco. "Most of us came from somewhere else and had an amazing arrival experience that was transformative. We became our best, truest selves, and it was magical and beautiful. But we cling to the San Francisco that was here when we arrived," Tumlin says. "I escaped a place that was oppressive and conformist and had this astonishing coming-out experience, but one that was extraordinarily self-involved. There is an upside to conformist societies: They tend to be communitarian, especially if you are in the in-group."

That's an extraordinary critique, not just of San Francisco but of the California dream. Tumlin is saying that to have the cities we need, we need to let go of the cities we have. The ideal city is a place where lots of different kinds of people with lots of different amounts of money can live and work. It has to be easy to get around without a car, even for people whose bodies can't ride bikes or hop over potholes, and for people who have kids to drop off on the way to work and groceries to buy on the way home, and maybe flowers to buy next door to the dry cleaner's. These are places where people want to live, because it's nice there. The fact that those places also adapt to and mitigate climate change instead of causing it is a bonus.

Tumlin and his generation of planners are offering a new vision of what broke American civil society. The culprit wasn't rock and roll or miniskirts or hippies. It wasn't immigrants or violent comics or violent TV or violent videogames or drugs or feminism or atheism or Fox News or cell phones or Russian hackers or even Dungeons and Dragons.

It was just cars.

ADAM ROGERS *(@jetjocko) is a senior correspondent who covers science and culture.*

_Of course e-scooters have no tailpipe emissions, but a study found that greenhouse gases from manufacturing, collection, and charging make them less green than most bus, bike, moped, and walking trips, thanks largely to vandals who cut the scooters' lives short. Boosting their life spans to two years would make the greatest carbon-cutting difference.

→ 2-3% PORTION OF GLOBAL GREENHOUSE GAS EMISSIONS GENERATED BY CARGO SHIPS

The Shipping Point

_Cargo vessels burn some of the dirtiest fuel there is and belch huge amounts of carbon. But their industry is poised for a dramatic shift.

BY Samanth Subramanian

ILLUSTRATION BY Eiko Ojala

STEFAN EEFTING IS, AS HE PUTS IT, "a long-lasting guy" in the shipping industry. He started as an apprentice engineer in a German shipyard in 1984, and now he's a senior vice president at MAN Energy Solutions, a firm whose engines power every second vessel on the deep seas. Over the course of Eefting's career, he's watched ship engines grow from massive steel contraptions to epically huge ones: The 100,000-horsepower monsters in today's cargo ships are five or six times the size of a house. And for decades, the vast majority of them have ingested heavy fuel oil—the leftover dregs of petroleum distillation, a product so viscous it's practically a solid at room temperature. "Like chewing gum," Eefting says. "You have to heat it to 140 or 150 degrees Celsius to even load it into the engine."

Heavy fuel oil burns thick and dirty, throwing off oxides of nitrogen and sulfur and producing more carbon emissions than almost any other fossil fuel. But it's cheaper than anything else on the market. When fuel is your industry's greatest cost—and when your industry guzzles 300 million metric tons of it a year—heavy oil is practically the only choice on the menu.

That calculation changed, however, on January 1, when a new international regulation mandating low-sulfur fuel kicked in. Ship owners must now either install devices to scrub sulfur out of their heavy fuel oil exhaust or buy cleaner, more expensive fuel—at $600 or $700 a ton, compared to $400 a ton for heavy fuel oil. And that rule is just a foretaste of a massive transformation that is bearing down on Eefting's industry.

Since the 1990s, ship owners have come under intense pressure to pollute the planet less. Container ships are indispensable to trade, and there's no greener mode of transport to move a freshly riveted pair of jeans from China to the US. But the world's 90,000 or so cargo ships contribute between 2 percent and 3 percent of all greenhouse gas emissions—more than the share contributed by Canada or Germany.

While the sulfur cap is hitting shippers now, the far more daunting and impressive target is 30 years away. By 2050, the United Nations' International Maritime Organization (IMO) has stipulated, the shipping industry's total emissions must be at least half of what they were in 2008. That goal is even more ambitious than it might sound. Trade will continue to grow even as 2050 approaches, says Johannah Christensen, the managing director of the nonprofit Global Maritime Forum. There will be many more ships at sea, making many more journeys, than there were in 2008. "What that translates to is actually an 85 percent reduction in emissions intensity per ship."

Meeting the deadline will require the industry to spend as much as $1.4 trillion on new fuel research and production, rejigged supply chains, and a revamped fleet—and no one even knows which solutions will work. The ambition, Christensen says, is "like a moon shot."

In some ways, it's easier to decarbonize shipping than, say, automobiles or cement. The number of cargo ships in the world is small enough for them to be individually tracked, and they live so much of their lives in public—being inspected in one international port or another—that they can't slyly break rules the way a cement plant in a corrupt country might. Further, the ships are already regulated by a central authority: the IMO. The nature of this industry—in which ship owners routinely register their vessels under the flags of small countries with lax regulations—also means that the IMO is the rare forum where island nations threatened by rising seas hold significant sway. "Depending on the day you look at it, the Marshall Islands is the second- or third-largest flag register in the world," says Bryan Comer, a senior researcher at the International Council on Clean Transportation. "And they were instrumental in making the moral argument for reducing emissions at the IMO. If they'd had their way, in fact, they'd have wanted a 100 percent cut, and much before 2050."

Even so, it's an unusual challenge for an industry to adopt an emissions target while having no clear notion of the technologies that will get it there. Borrowing ideas from other sectors isn't practical. Batteries are out. A container ship crossing the Atlantic would need so many batteries that it would have no room left for containers. Nuclear power, too, is dead in the water—"for political reasons," says Simon Bennett, the deputy secretary general of the International Chamber of Shipping. "The idea of foreign ships coming into your port with a nuclear reactor on board—that just won't be acceptable."

The solution most immediately at hand, liquefied natural gas, emits less carbon dioxide than fuel oil, and ship engines can be retrofitted fairly easily to burn it. But carbon emissions from liquefied natural gas are only about 30 percent less than from heavy fuel oil. What's more, the primary component of liquefied natural gas, methane, is highly prone to "slip," or leak. Atmospheric methane traps 86 times more heat than carbon dioxide over a 20-year period. At best, says Eefting, liquid natural gas is only a temporary answer—an intermediate station on a zero-carbon pathway.

The fuels with more long-term promise are ammonia and hydrogen, which, when burned, release no carbon emissions at all. MAN plans to deliver its first ammonia engine in 2024. But there's still plenty to be figured out: To be truly green, these fuels will themselves have to be manufactured with no carbon footprint—something the IMO can't regulate. Ammonia production is one of the most carbon-intensive processes in industrial chemistry and is the subject of its own slogging race for sustainable modifications. Meanwhile, ships and ports will have to devise new ways of handling and storing ammonia, given how toxic it is to humans. "Plus, you have to remember," Eefting says, "ammonia stinks very much." Hydrogen, for its part, is highly flammable and would require huge, special tanks. "Its molecules are so small that they can leak out of virtually anything," Eefting adds. "And you need to compress it or cool it to minus-253 degrees Celsius to have a decent energy density."

The year 2050 isn't so distant. Ships have such long life spans that, for the fleet to be ready in time, new vessels entering the water as early as 2030 must already be configured for zero-carbon fuels. More than the tech, though, it's the IMO's model of curbing emissions that feels both uncommon and important: Lay down the standards first, regulate the consumers—the ship owners—and trust that they'll compel their fuel and engine suppliers to invest and innovate. Tristan Smith, a low-carbon shipping expert at University College London's Energy Institute, says that the response since IMO adopted these targets has been extraordinary. "The speed with which energy manufacturers have moved, ammonia suppliers have moved, ship owners have moved—nobody would have believed it 18 months ago." If the model succeeds—if it isn't subverted by fossil-fuel giants or cheating ship owners—it'll hold a lesson for other sectors, Smith says. "When you regulate sensibly, the market will supply the answers."

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Tech We Need

Silicon Valley, if you're listening here's how you can help:

—

An Instagram algorithm that boosts influencers who post pics of themselves riding public transit instead of jetting to Reykjavik.

—

A holodeck for business meetings, eliminating more than 400 million miles of annual travel by US workers alone.

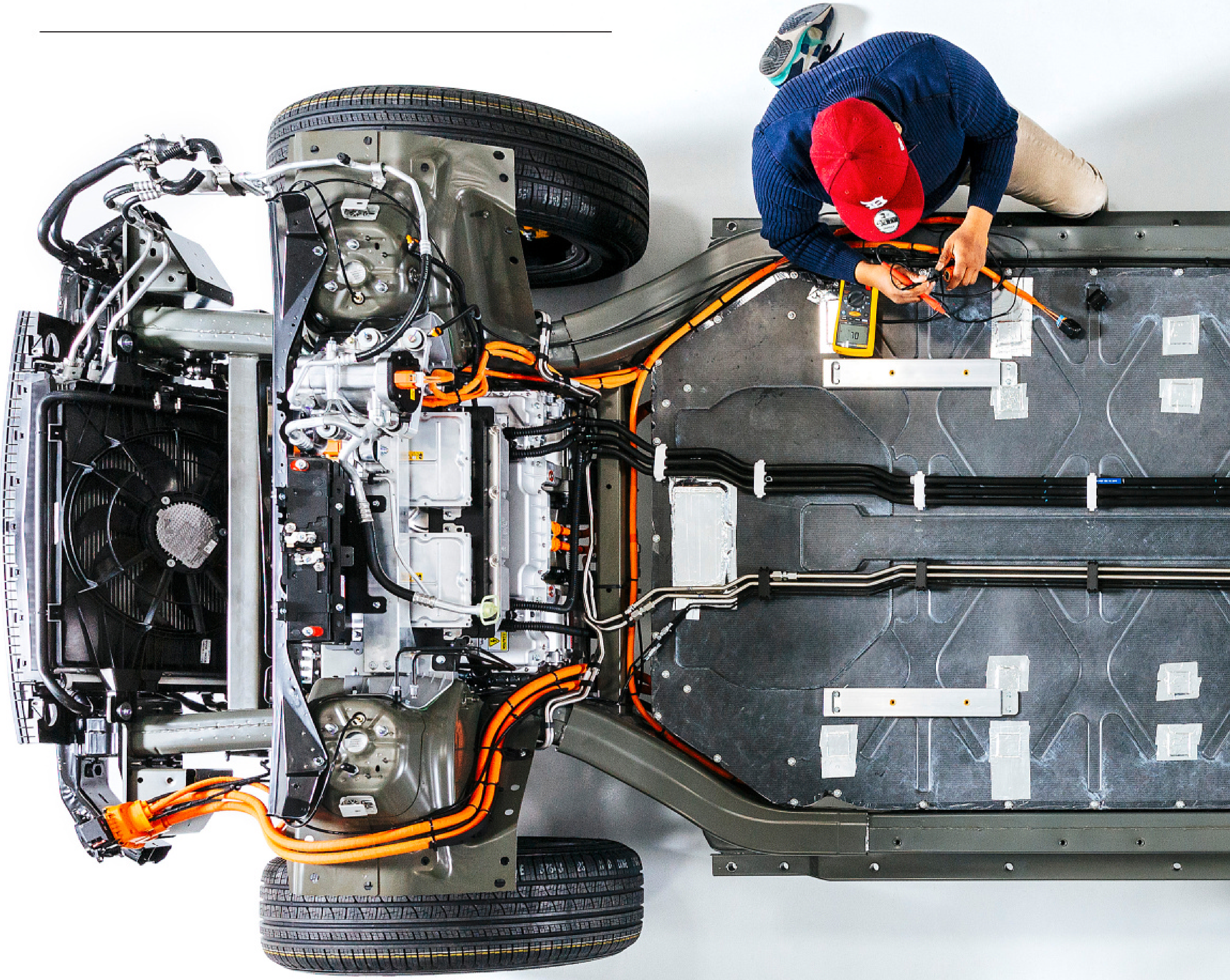
—

Cheap 3D printing for furniture, which just beats out bananas as the US' biggest import by weight.

—

Local, lab-grown bananas.

→ **19%** INCREASE IN THE ENERGY SECTOR'S CARBON EMISSIONS CAUSED BY SUVS ALONE IN THE PAST DECADE



The Body

BY Jon Gertner

PHOTOGRAPHS BY Cayce Clifford

Electric

_Can automotive upstart Rivian break America's addiction to carbon-spewing pickups and SUVs? With Amazon on its side, it might have a chance.

DURING THE SUMMER OF 2006, BACK WHEN RJ Scaringe was working through a degree in automotive engineering at MIT, he began to wonder how difficult it might be to live within strict environmental boundaries. How much would you have to change—and how fast, for how long—if you desired to wipe away the carbon traces of your everyday life? Scaringe decided to conduct an experiment, using himself as the subject. For months, he walked, biked, or used public transportation wherever he went. He took cold showers, washed his laundry by hand, and traded his dryer for a clothesline. When he ate out, he brought his own spoon, to cut down on plastic waste.

"I was tracking the data really closely," Scaringe, a soft-spoken, genial sort with Clark Kentish glasses and short dark hair, told me recently. By summer's end he had reached two conclusions. The first was that he still had a meaningful carbon footprint. The second was that he was disheveled and uncomfortable. "I said, holy smokes, no one will sign up for this, and if this is our plan to address climate change, we're going to lose," he recalled. Asking billions of people to don an unwashed hair shirt wouldn't work; the solution would have to be rapid technological innovation.

Several years later, PhD in hand, Scaringe founded an automotive company called Rivian, named for the Indian River in Florida, near where he grew up. He'd spent his teenage years rebuilding classic sports cars and now hoped to produce a modern one of his own, powered by a hybrid system. "Almost from the very beginning, I knew in my heart something was wrong," he said. The hybrid seemed lacking in higher purpose, and it could have limited financial potential. As Scaringe put it, "The product we were building was really failing to answer the question of: Why do we need to exist as a company?"

The answer came two years later, at the end of 2011. With Tesla poised to release the Model S, which would dominate the market for high-end electric sedans, Scaringe told his team it was time to pivot to trucks and SUVs. They might be less exciting to build than glossy roadsters, but they'd give the company an existential purpose. At the time, light-duty vehicles—the Environmental Protection Agency's catchall term for cars, trucks, SUVs, and minivans—accounted for more than 60 percent of the country's transportation emissions. Trucks were the thirstiest gas drinkers of them all, with EPA ratings that had hovered between 16 and 19 miles per gallon for the previous 30 years. Yet along with SUVs, they were also among the most popular vehicles on the road.

It has taken Scaringe more than a decade, but at the end of this year, Rivian's first pickup truck, the R1T, will begin rolling off the production line in Normal, Illinois. A sister SUV, the R1S, will follow in early 2021. The wisdom of the company's pivot is now clear: In 2019, the best-selling vehicles in the United States were the Ford F-150 (896,526 sold), the Dodge Ram (633,694), and the Chevy Silverado (575,600); the next four on the list were all SUVs. And according to the International Energy Agency, SUVs alone have done more to increase CO_2 emissions in the past decade than planes, cargo ships, or heavy industry. The market is there, in other words, but it hasn't yet proved willing to enter the 21st century.

The R1T and the R1S are pure battery electrics. They're targeted less toward construction workers hauling tools than hikers taking a Subaru into the Sierras on weekends. This is by intention. Scaringe, who has read a psychographic profile or two, estimates that only around 10 percent of pickups sold in the US are used strictly for work. Many now come loaded with luxury flourishes and roomy cabins and chromium baubles. Owners drive them not around the ranch but to football games on weekends and the office on weekday mornings. Rivian designed the R1T for this 90 percent, with a focus on what Scaringe calls "ride quality" and "a demonstrably better driving experience." The pickup walks a careful line between Detroit traditionalism and EV iconoclasm. Where Tesla's forthcoming Cybertruck looks like origami on wheels, the R1T, slim and limber, looks more like an F-150 on a gym-and-yoga regimen.

Rivian is seeking adventurous buyers—or those aspiring to *appear* adventurous, anyway—who can afford to shell out around $60,000 for an entry-level model. That's about a third more than they'd pay for an equivalent gas- or diesel-powered pickup, although the higher sticker price is offset to some degree by federal EV tax credits, state rebate programs, and lower lifetime fuel costs. What they'll get for their money is a truck that, depending on battery configu-

Where Tesla's Cybertruck looks like origami on wheels, Rivian's electric pickup, slim and limber, looks more like a Ford F-150 on a gym-and-yoga regimen.

_Fifty electric school buses are rolling into Virginia this year. The fleet could grow to 1,500 by 2025—a small but promising step away from diesel, which powers the rest of the nation's 480,000 school buses.

ration, can go up to 400 miles on a single charge and accelerate from 0 to 60 in as little as three seconds flat. The R1T is rated for towing 11,000 pounds, making it easily as muscular as a no-frills F-150 or Ram. Some models can even, upon command, execute a stand-in-place, 360-degree "tank turn." All Rivians will come equipped with semiautonomous modes and an Alexa assistant. And, like Scaringe himself, the upholstery will be vegan.

The company still faces a climb of extraordinary technical and economic difficulty. Relaxing one afternoon at Rivian's engineering and design center in Plymouth, Michigan, Scaringe, now 37, ticked off a list of obstacles. There is, first of all, the challenge of appealing to truck traditionalists. Some buyers, one auto analyst told me, might be unwilling to give up the ineffable feeling of "truckness" they get behind the wheel of, say, a Silverado. And even green fanatics aren't guaranteed customers: So far, any electric vehicle that doesn't have the Tesla badge has found it nearly impossible to gain a foothold in the American market, with sales of non-Tesla EVs actually declining last year across the board. Meanwhile, a host of new competitors—including Arrival, a startup backed by Kia and Hyundai, and Bollinger, whose vehicles resemble boxy, retro Jeeps—are nipping at Rivian's heels.

To Rivian's good fortune—or, possibly, its utter ruin—it has the support of a wealthy, well-connected patron. Last year, at a press conference in Washington, DC, Jeff Bezos announced what he called the Climate Pledge, committing Amazon to weaning itself off fossil fuels by 2030. To meet its goal without delaying world domination, the company will need an immense new fleet of zero-emissions delivery vans. Rivian has committed to designing and building the first 10,000 for Amazon by 2022, with another 90,000 due by 2024. There will be little room for failure, Scaringe says: "We *cannot* be late in delivering those vehicles."

RIVIAN'S HEADQUARTERS ARE LOCATED ON the outskirts of Plymouth, a small city 30 minutes west of Detroit, in a refurbished factory that once produced compasses, gunsights, and adding machines. The offices—home to about 800 employees, with the rest of the firm's 2,000 workers situated in Illinois, on the West Coast, and in Europe—are brightened by whitewashed walls and high clerestory windows. Rivian has installed display tables along the periphery, filled with hundreds of items (carabiners, US National Park stickers, chic rucksacks, mesh sneakers, titanium camping mugs) that are meant to remind employees of the sort of customer they're aiming to entice. In a central atrium, sunlight pours down onto a silver-blue prototype R1T, a point of keen interest for visiting parts suppliers. Arguably, though, it's the Amazon van, parked a few feet away, that may drive the company into viability.

The van isn't real. It's made of clay and wrapped in blue plastic. Rivian's actual Amazon prototypes remain mostly in stealth mode while the companies sort out design requirements and technical specs. Once that process is complete, the largest hurdle for Scaringe's team will be mass manufacturing—a challenge so difficult it nearly broke Tesla during its scale-up of the Model 3, leading Elon Musk to camp out at his factory overnight. Rivian's task may be even harder than Tesla's was: The company must produce a truck, an SUV, and a huge fleet of vans without ever having made a single car. And that's just in the next couple of years. While no timeline has been announced, the firm also plans to make a large SUV for Ford-Lincoln and a small SUV under the Rivian brand.

The link between these projects—the feat of engineering that makes them conceivably doable—is Rivian's so-called skateboard chassis. The company takes a single common platform, adds various combinations of battery packs, drivetrains, and motors, then "top-hats" the vehicles with different bodies to create distinctive models. The skateboard isn't quite one-size-fits-all: The Amazon van has by far the largest chassis, and the R1S the smallest. But the basic engineering is the same. As Michael Bell, who oversaw software development for Rivian until February, told me, "having a well-documented, defined, abstracted platform allows you to just move *faster*." In theory, the company can use its standard dough recipe to make any size pizza, with any kind of toppings, and do it exceedingly quickly.

The responsibility for integrating these platforms and vehicle designs falls mainly on Mark Vinnels, Rivian's chief engineer. Vinnels, who came to the company two years ago from McLaren, the luxury British sports car builder, is usually in one of two places—test-driving prototypes at the Toyota Arizona Proving Grounds or taking meetings in his office in Plymouth. He speaks with a thick English accent and at a clip that approximates a McLaren roadster's. When I visited him in Plymouth, he said he was going "1,000 miles an hour," racing to complete technical sign-off on the R1T. There were crash tests to run, range numbers to confirm with the EPA, components to check for quality and durability. But Vinnels didn't seem especially concerned. "With the skateboard, you can pretty much put a seat and a steering wheel on this and drive it away," he said. He paused, then asked, "Do you want to go see some hardware?"

We walked through a set of double doors to Vinnels' engineering shop, an enormous, high-ceilinged room populated with Rivians in various states of undress. Some were what the company calls mules—prototypes hidden beneath the carapaces of old Ford F-150s so that they could be driven around in public without attracting attention. Vinnels led me past a dirt-encrusted R1T that was raised on a lift for inspection; it had just arrived home after a 105-day journey from the tip of Argentina to Los Angeles. When we reached the skateboard, Vinnels crossed his arms and pointed out the com-

_NASA's all-electric X-57 Maxwell plane, powered by lithium-ion batteries and 14 propellers, will take its first flight later this year, potentially marking the dawn of ultraquiet air travel.

ponents one by one. The frame was made from olive-green square steel tubing and sat on four fat Pirelli tires, with gearboxes and inverters at the front and back. There was a broad platform in the middle for the batteries, which were wrapped in ballistic and waterproof materials. The wheels each had their own motor, allowing them to move independently—the secret to the tank turn.

Part of Rivian's goal with the R1T is to persuade the public that electric trucks can have truckness too. The Amazon project presents an altogether different sort of challenge. Instead of torque and horsepower, Vinnels said, his team has spent its time on efficiency—trying to save drivers precious seconds when they get up, grab a package, and exit. The effort, which involved Rivian engineers tagging along on Amazon vans, seems to have resulted in a complete ergonomic rethink of the delivery regimen. It has meant redesigning the cabin egress, driver's seats, dashboard controls, and shelving in the van's cargo space, all with the intention of shaving fractional bits of time—and millions of dollars—from the process.

Once the vans are on the road and gathering data, Rivian will learn valuable information about, say, which parts are most prone to wear out or which bit of code needs patching. And whatever Rivian learns from its vans could well inform its trucks and SUVs. They're all in this together.

YEARS AGO, I HAD THE CHANCE TO VISIT Tesla just before the launch of the Model S. It is difficult to recall now just how few observers of the staid automotive market believed the company would survive. Perhaps in response, the mood in Palo Alto in those days was intense, anxious, and righteous. Those I spoke with worried about what Musk, the maximum leader, might think of a new trim detail or manufacturing hiccup. In retrospect, perhaps that's precisely what the company needed to succeed and to clear the path for other EV makers. Tesla was an army, following a general, marching headlong into battle.

Rivian isn't like that. The mood at the company is intense; the hours are long and punishing. But there is a lightness and optimism in the ranks, even with the monumental challenges at hand. Scaringe told me the complexity of his firm now vastly exceeds his teenage dreams of what a car company would be like. "It's good when you're a kid, when you're young, to believe that things are easier than they are," he said. "Thousands of moving pieces, literally and figuratively, have to link together, and if one of those isn't working properly it can upset the whole system."

Musk has said, as red-blooded CEOs often do, that he welcomes competition. In his case, the sentiment appears to be driven by a genuine concern for the planet. Quarterly earnings reports aside, Tesla's deeper mission—its existential purpose—is to "accelerate the advent of sustainable transport," Musk wrote in 2014. That probably wouldn't mean a Model S in every garage, he seemed to admit; rather, what the auto industry really needed was "a common, rapidly evolving technology platform." Musk thought Tesla would supply the platform. Six years later, Rivian may deliver it instead. The big question, then, isn't whether Scaringe can unseat Musk as commander in chief of the EV market. It's whether Rivian, with its skateboard, can help a number of big manufacturers buy into clean transportation with ease and confidence, and thus hasten the end of humanity's reliance on the internal combustion engine.

To be sure, this is not the only path forward. John DeCicco, an associate director of the University of Michigan Energy Institute, pointed out to me that if the EPA raised fuel-efficiency standards in gas pickups, the result would be huge, rapid emissions reductions. For now, though, federal regulators in the Trump administration seem to be moving in the opposite direction. And the long-term problem remains: Transportation accounts for nearly a third of US greenhouse gas emissions, more than any other economic sector.

Like Musk, Scaringe does not think his company alone can solve the problem. He is eager to say that the transportation market is so large it will need other EV competitors joining in, along with a grid providing abundant electricity produced from clean energy sources. Yet he acknowledges that he won't make any impact at all if his trucks

The Competition

TESLA CYBERTRUCK

Jokes abounded last fall when Elon Musk unveiled Tesla's new *"Blade Runner pickup,"* but the Cybertruck can drive up to 500 miles on a single charge and is available with one, two, or three motors. With all three, Tesla claims, it can tow 14,000 pounds and bolt from 0 to 60 in 2.9 seconds.

BOLLINGER B2

In 2021, Detroit-based startup Bollinger will begin offering a four-door, 614-horsepower pickup that seems designed exclusively for an eco-conscious Batman on safari. The charge lasts for some 200 miles, and the starting price is $125,000.

ELECTRIC FORD F-150

Ford has stayed mum on specs, but electric F-150s are expected sometime in 2021. Last summer a prototype towed a million-pound freight train loaded with conventional F-150s.

ATLIS XT

Arizona-based Atlis is building an ultra-rugged pickup that can reach 120 mph, last up to 500 miles, and charge in 15 minutes.

Last fall, the Norwegian cruise line Hurtigruten debuted the world's first hybrid cruise ship, which emits 20 percent less carbon than traditional vessels. The company is retrofitting six ships to run on batteries, natural gas, and unwanted dead fish from local fisheries, which are converted into liquefied biogas—and de-stunk in the process.

THE R1T HAS A STORAGE SPACE (OR "GEAR TUNNEL") WHERE THE GAS TANK WOULD NORMALLY BE. RIVIAN WILL MAKE A SLIDE-OUT CAMPING KITCHEN AVAILABLE AS AN ACCESSORY.

and SUVs appeal to buyers only for reasons of sustainability. The lessons of the summer of cold showers in Boston linger.

In Plymouth, Scaringe walked with me out to the atrium, where the Rivian pickup was parked, to make his point. "What do you think?" he asked.

The question was expected. Scaringe goes to just about every customer event the company holds around the country, hoping to gauge people's reactions. His truck looked good—there was no way around that. It was sleek, modest, inviting. If I lived out West, I thought, I wouldn't mind driving it through a babbling brook on the way to a campsite.

To Scaringe, this vehicle seemed less a piece of electromechanical hardware than the end product of 10,000 difficult decisions that had to be made with consistency and rigor. When you're talking to customers, he said, you'll find that one needs the truck bed to be short, to fit in the garage, and another needs it to be long, to haul gear. (The R1T's bed expands from 4' 11" to 6' 11".) The same goes for countless other small matters—"and each person is sure they're 100 percent right," Scaringe said. He shook his head, as though still amazed by the machine in front of us. His intent is that the truck of 10,000 decisions will delight everyone and tread lightly on the earth—but do so with a great deal of traction. The hope, in short, is that it might, as it begins rolling off the factory lines in a few months, do it all.

JON GERTNER *(@jongertner) is the author, most recently, of* The Ice at the End of the World: An Epic Journey Into Greenland's Buried Past and Our Perilous Future. *He wrote about a melting Antarctic glacier in issue 27.01.*

_China's new magnetic levitation train, the world's fastest, will reach speeds of 373 mph, carrying passengers more than 600 miles in two hours while putting out less than half the emissions of a regional flight.

→ **2.5%** PORTION OF GREENHOUSE GAS EMISSIONS GENERATED BY AIR TRAVEL—A FIGURE THAT IS EXPECTED TO GROW

Altitude Adjustment

_Winglets. Better engines. Lighter materials. The airline industry is trying everything to increase fuel efficiency and cut emissions. But the best fix would be for us to stop flying so much.

BY
Christie Aschwanden

ILLUSTRATION BY
Jan Siemen

"WE WILL NOT HAVE TO STOP AIR TRAVEL, BUT we will have to plan for it more carefully," President Nixon told the nation in November 1973. Schedules would be reduced, loads increased, and the use of fuel for aviation cut by 15 percent. Then, as now, we faced a crisis over energy. Nixon's speech followed the OPEC oil shock, but concerns about the climate were already growing. (Scientists would begin to reach consensus on the basic facts of global warming by decade's end.) So an urgent problem came to Richard Whitcomb, a decorated NASA engineer at Langley Research Center in Virginia: Might there be some cheap and easy way to make flying more efficient?

In 1974, Whitcomb started playing with an old idea—that you could gain energy efficiency just by bending up the tips of airplane wings until they were almost vertical. After modeling the idea and testing it in wind tunnels, Whitcomb estimated that the "winglets" he'd designed could reduce the use of fuel by 6 to 9 percent. Real-world trials of a Boeing 707 confirmed the lab's success.

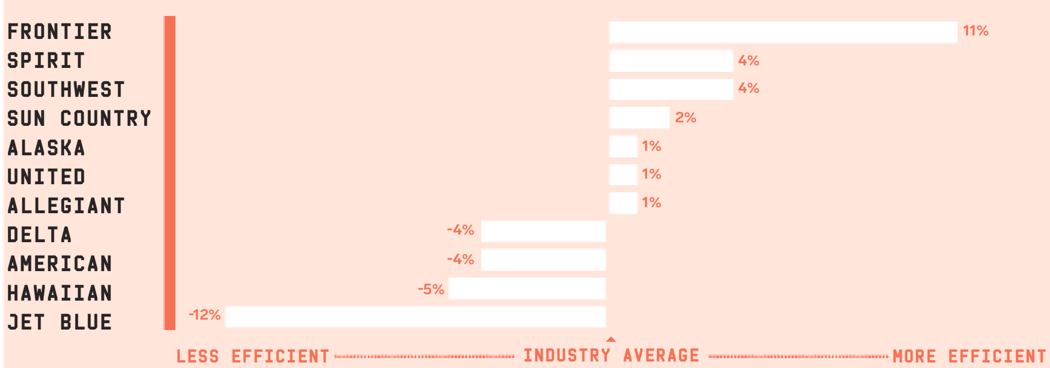
Whitcomb's winglets now stand among the key technologies that have helped US airlines to increase their fuel efficiency by 130 percent over the past 40 years. Further gains, these days, are generally accomplished in one of two ways: Planes are either redesigned from scratch, like the Boeing Dreamliner 787, with more aerodynamic airframes, lighter materials, and better engines; or they're upgraded with the most efficient engine an existing airframe can accommodate. Careful application of the former method yields up to 27 percent improvements in efficiency; the latter, maybe half that.

Even so, our world of winglets doesn't get us far enough. Improvements to air traffic control could also help reduce emissions by as much as 12 percent, per a 1999 estimate from the Intergovernmental Panel on Climate Change. But a more recent analysis suggests that we've accomplished half of that already, and may not get much further without slowing flights or compromising safety. Still, a major air traffic control project from the Federal Aviation Administration, called NextGen, aims to implement more efficient GPS-based routes and reduce energy-wasting traffic jams in the air and on the tarmac.

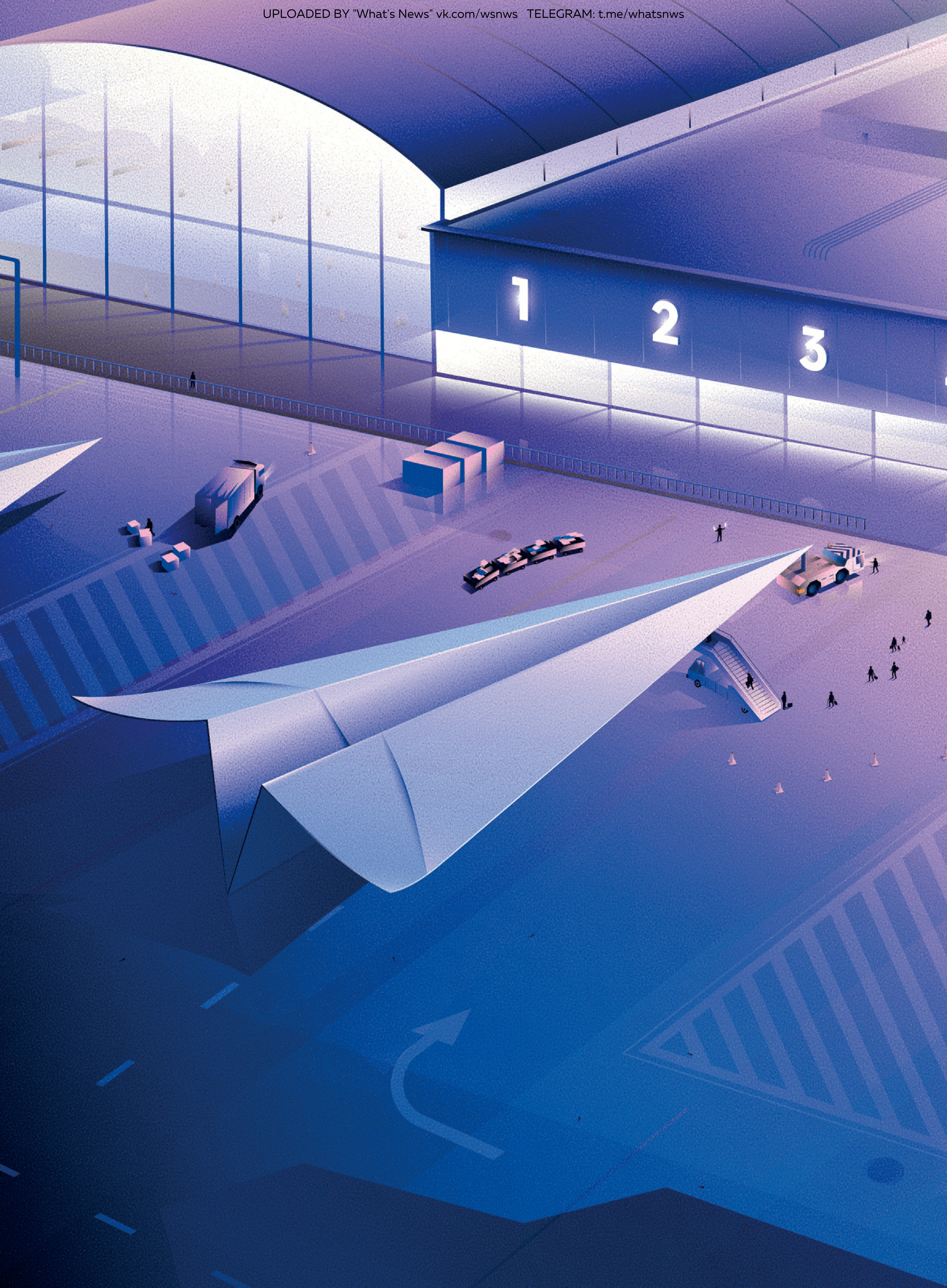
Airplane fuel could itself be more efficient. The aviation industry has made a lot of noise about adopting "sustainable" fuels made from things like algae, plant oil, food waste, and gas captured from landfill emissions.

If You Must Fly ...

Before you book, consider the carbon cost. No US domestic airline is green by any means, but Frontier made the most efficient use of fuel in 2018—11 percent better than the industry average.



Source: The International Council on Clean Transportation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In principle, the use of biofuels like these could reduce greenhouse gas emissions. For that to happen, though, they'd need to be much cheaper, available at scale, and generated in sustainable ways. In 2010 the airlines' trade association set a goal of drawing 10 percent of the industry's fuel from sustainable sources by 2017; in 2018 such fuels represented only 0.002 percent of the total.

In spite of some real improvements, the airplane emissions crisis hasn't gone away. In fact it's getting bigger every day. Whatever efficiency gains we get from newer planes with bent-up wings, better traffic management, or biofuels have been overwhelmed by the fact that people are flying a lot more. Passenger numbers are expected to nearly double by 2037, while airlines' fuel efficiency is improving by only 1 or 2 percent a year. The UN's International Civil Aviation Organization forecasts that by 2050, global international aviation emissions could balloon by 300 to 700 percent. Maybe Nixon had it right: We may not need to stop air travel altogether, but we sure need to scale back.

CHRISTIE ASCHWANDEN *(@cragcrest) is an Ideas columnist for* WIRED*.com*

Flight Plan

For help identifying the least terrible ways to take a plane, the International Council on Clean Transportation's Dan Rutherford has devised a mnemonic: "Fly like a NERD."

N IS FOR NEW:
Book your flight on newer, more efficient aircraft.

E IS FOR ECONOMY:
Economy-class cabins, with denser seating plans, produce fewer emissions per passenger.

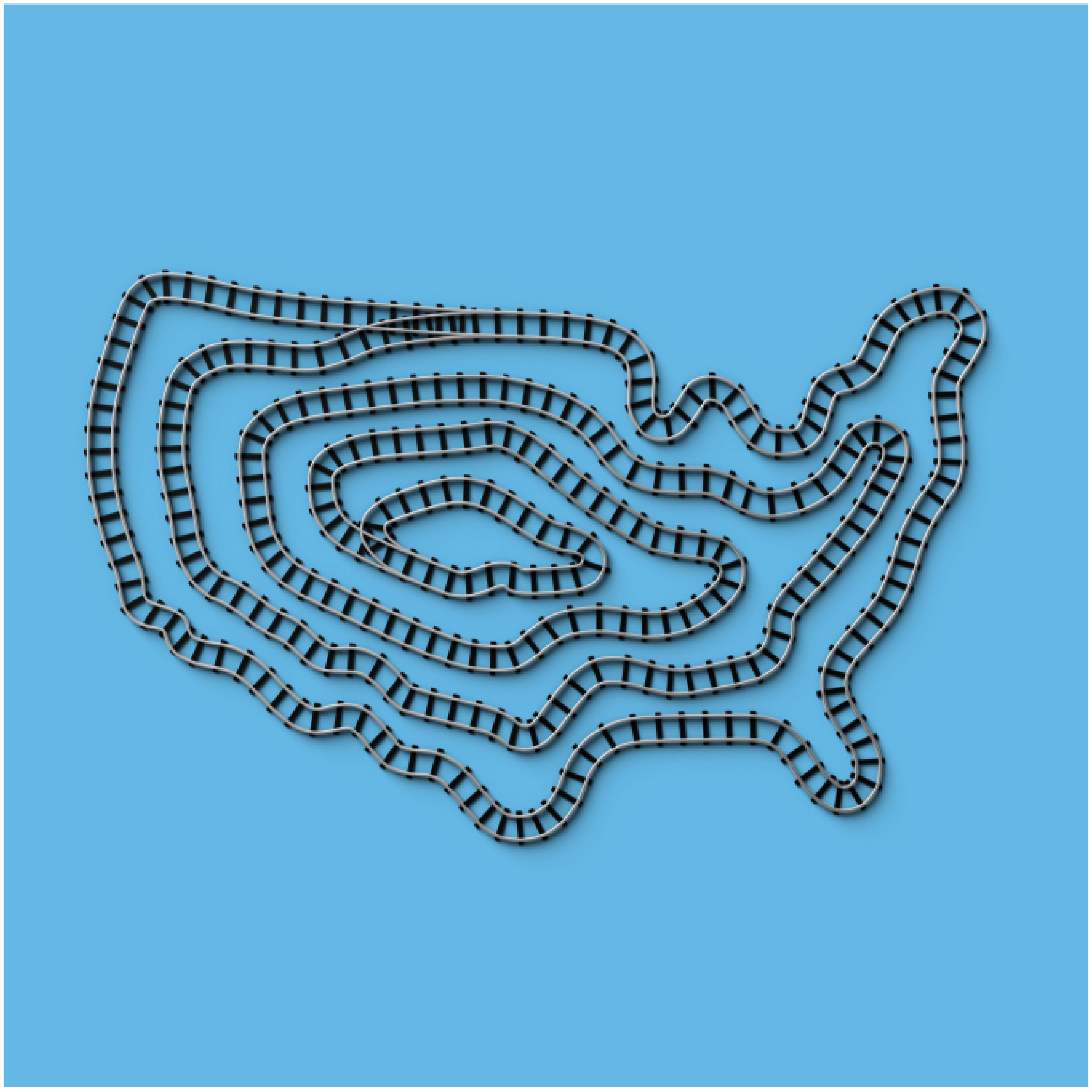
R IS FOR REGULAR:
Average-size planes, as opposed to small or jumbo ones, tend to get the best mileage.

D IS FOR DIRECT:
Nonstop saves fuel.

Airlines don't always make it easy to follow this advice. You can't filter flights by airplane age or size. But ICCT has tracked overall airline fuel efficiency in the US since 2010, and its latest ratings show there's a pretty wide gap between the best and worst. (See chart on previous spread.)

Extra Terrestrial

_Some environmentally conscious people are trying to give up flying. For many trips, there's a great, cleaner alternative: It's called a train.



BY Alex Davies

ILLUSTRATION BY Alvaro Dominguez

IT STARTED WITH THE CALIFORNIA FOREST fires. Ariella Granett lives in Berkeley, and stapling a paper smoke mask to fit her 8-year-old daughter's face made the planet's ills feel personal. Then, last spring, her son came home from school and announced the world was ending. His seventh grade class was told that by 2030 the harm done by climate change could be permanent. "I couldn't soften that," Granett says.

Granett rode her bike, ate little meat, composted food and garden waste. But faced with an alarmed tween, she resolved to take more drastic action. That summer, she quit flying. Soon after, with her husband, she cofounded Flight Free USA, a satellite of Sweden-based We Stay on the Ground.

At climate rallies, Granett entreats strangers to keep it terrestrial. She's got the stats: Flying accounts for 2 to 3 percent of all greenhouse gas emissions, not counting the extra damage done by burning fossil fuels at 30,000 feet. Carbon offsets don't help much. Capable electric aircraft are decades away. So the flight-free folk argue that the only good flight is one that never takes off.

Across Europe, this movement is gaining traction. ("Denmark to Japan by train—what is the cheapest option?" asks Tobias H. on a Tripadvisor forum.) Maja Rosén, who cofounded We Stay on the Ground in 2018, has reined in her wanderlust and now vacations by ferry and train, mostly in Sweden, where she lives. "I would love to go to the moon as well," she says, "but I don't walk around thinking it's such a shame I can't."

Climate-conscious European governments have helped by imposing new taxes. Germany has been especially aggressive, nearly doubling its per-passenger tax on short-haul flights while slashing taxes on train travel. The head of the EU Commission is pushing for a jet-fuel tax that could boost fares 10 percent. Such moves are easier on a continent with a robust rail network, including high-speed trains that zip from London to Paris to Milan to Vienna to Budapest.

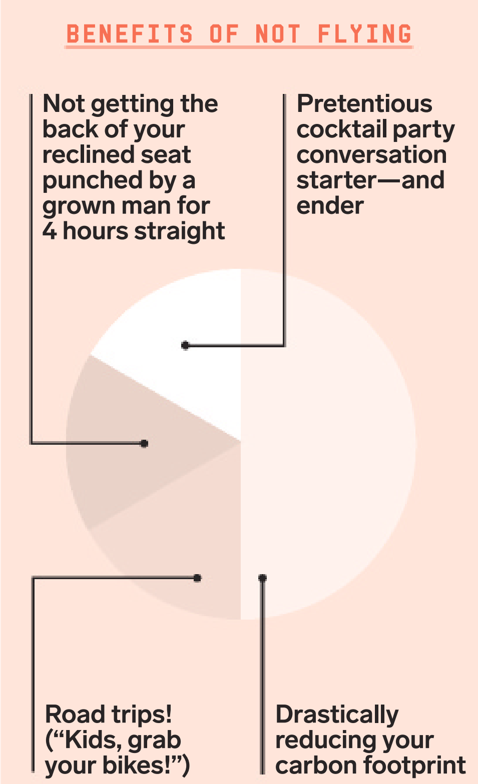
Getting around the US on a train, by contrast, is an iffy endeavor. The US has a thin rail network and a shoddy record creating better trains. We have little to show for $10 billion allocated a decade ago for a new generation of high-speed railroads. A chunk of that money went to a planned high-speed line connecting San Francisco to Los Angeles; it's far behind schedule and over budget.

Granett is disappointed by the long wait for that California train. But even so, she says, "it feels like choosing train over plane is voting with our dollars for investing in sustainable infrastructure."

Existing train lines can replace shorter flights that are especially tough on the planet. Regional flights (think Los Angeles to Las Vegas) burn twice as much fuel per passenger-mile as medium-haul flights (LA to Chicago), according to the nonprofit International Council on Clean Transportation. In the Northeast corridor between New York and Washington, Amtrak riders outnumber fliers by more than two to one. The emissions savings are significant. Oak Ridge National Laboratory estimates that Amtrak is 33 percent more energy-efficient than flying on a per-passenger-mile basis.

Chartgeist

BY Jon J. Eilenberg



To extend that benefit, Amtrak could increase service in other regions laced with little-used rail lines—Chicago to Cincinnati, Minneapolis to Milwaukee, Atlanta to New Orleans. It could use some help, though. Freight train operators, who own most US tracks, frequently fail to give passenger trains the right of way, prompting 20,000 hours of Amtrak delays in 2018.

Better yet, railroads could go electric. That would be expensive: running catenary wires, building substations, and upgrading tracks costs, on average, $2.5 million per mile. And it only makes sense over longish distances. Do the work, though, and trains can run faster, cleaner, and cheaper. And those wires could do double duty, moving electricity from the remote areas where solar and wind power are easy to produce but hard to pipe into the grid.

Back in Berkeley, Granett suits up to bike through the rain to her Oakland office. Six feet tall with reddish hair, she speaks quietly but passionately. Her organization asks people to avoid flying for a year, figuring that's a doable ask and that the habit might stick. The worldwide goal was 100,000 pledges not to fly in 2020; the 24,000 people who enlisted as of February won't ground any planes. But the point is largely to make people realize the damage caused with every takeoff. Granett would like to see governments raise taxes on flights and require airlines to display emissions information before a customer clicks Buy—akin to car window stickers estimating fuel economy.

Granett has adjusted her lifestyle to her pledge. She quit the architecture firm for which she traveled several times a year and took a job focusing on affordable housing in the Bay Area. (Happily, the change didn't entail a pay cut.) Her family spent its winter vacation biking through San Francisco and Marin County. They're contemplating a road trip through Mexico or Canada.

Still, staying grounded has consequences. Granett can't visit her brother in Italy or sister-in-law in West Africa. (They Skype.) She misses weddings and bar mitzvahs on the East Coast. At least for now. She's placing the planet's future ahead of herself and anyone she might offend. "I just think about how little time we have," she says. "I'm thinking in emergency mode."

ALEX DAVIES *(@adavies47) runs the Transportation channel on* WIRED*.com.*

PROMOTION

FRIDAY

Yeah Yeah Yeahs
Angel Olsen
The Fiery Furnaces
Jehnny Beth
Deafheaven
Waxahatchee
Tim Hecker & The Konoyo Ensemble
SOPHIE
Fennesz
Hop Along
Dehd
SPELLLING
KAINA
Femdot

SATURDAY

Run the Jewels
Sharon Van Etten
Twin Peaks
Danny Brown
Thundercat
Cat Power
Tierra Whack
BADBADNOTGOOD
Dave
Oso Oso
Divino Niño
Boy Scouts
Ezra Collective
Margaux

SUNDAY

The National
Big Thief
Kim Gordon
Phoebe Bridgers
Yaeji
Caroline Polachek
DJ Nate
Maxo Kream
Rapsody
Faye Webster
Mariah the Scientist
Dogleg
The Hecks
Dustin Laurenzi's Snaketime

15th

Pitchfork Music Festival Chicago

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Tickets on sale now at pitchforkmusicfestival.com

"Even the president's hostility toward renewables can't halt investment in a device that turns sunshine into money." page 90

Renew

HOW WE'LL PUSH FOSSIL FUELS TO EXTINCTION

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Umbrella Policy
by Zak Jason and Anthony Lydgate
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The Shining
by Stephen Witt
p. 90

Solar Flair
by Clive Thompson
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→896 THE NUMBER OF TURBINES THAT ONE PRIVATE COMPANY PLANS TO INSTALL IN WYOMING BY 2026

Into the

Wind

_Wyoming should be a renewable energy juggernaut, but the state is dominated by fossil fuels. Next step: Thinking of the future instead of digging up the past.

BY Chris Outcalt

PHOTOGRAPHS BY Cody Cobb

A MASSIVE WIND TURBINE RISES INTO THE air about 60 yards from where I stand. Silhouetted against an endless blue sky, the structure is taller than the Statue of Liberty, and the tips of its three blades spin more than 150 miles per hour, fast enough to complete one revolution every four seconds or so. Looking up at it from the ground is disorienting; I feel as if I've shrunk. Even the Ford F-250 pickup I'm about to climb into—one of those monsters with a roaring engine and an extra bar to help you step up into the cab—seems miniature. I listen, but if the turbine itself is making a hum or whir, I can't hear it over the relentless pounding of the wind, a white noise accompanied by the sound of the air snapping against the loose fabric of my jacket.

Opposite me, on the driver's side of the pickup, is Laine Anderson, director of wind operations at PacifiCorp, a public utility company that powers more than 140,000 square miles across six Western states. As I move to hop in the truck, Anderson cautions me to watch my door. He's never actually seen one blow off a vehicle, but PacifiCorp does cover the possibility in safety training.

The wind farm we're touring today is called Glenrock, one of nine that PacifiCorp operates in Wyoming; they are among the more ideally situated wind farms in the US. Wyoming's topography—a series of mountain ranges and plateaus spread diagonally across the state—creates a sort of natural funnel. In some towns near the end of that funnel, the gusts are so strong and persistent that trees noticeably lean to the east. In fact, the wind blows harder and with more regularity here in south-central Wyoming than just about anywhere else in the US. And yet compared to Texas, Iowa, California, and several areas across the Great Plains, Wyoming lags far behind in wind development, ranking 16th for installed wind capacity. Glenrock stands in a state where renewable energy has been, if not quite embattled, then stigmatized and viewed with contempt. And the reason for this cold reception is, in a way, written on the landscape of Glenrock itself.

Anderson shifts the truck into gear and starts up a hill. Up high, you get a better sense of the wind farm's scope: 158 steel turbines that look like pinwheels copied and pasted into neat rows across 14,000 acres. You also get a sense of its backstory. Constructed in 2008, Glenrock was the first wind farm in the country to be built on top of a reclaimed coal mine—a feat of modern engineering that doubles as a particularly on-the-nose metaphor for the transformation that Wyoming has been reluctant to embrace. "Right here on our left, this was an open pit," Anderson says, pointing to a rolling field.

Wyoming's attachment to fossil fuels runs deep. For more than a century, roughnecks have been scraping through layers of Wyoming's topsoil, mining coal and drilling for oil. In the 1980s, the state's coal sometimes accounted for a quarter of the energy consumed by the entire country. Coal mining jobs brought pride and a middle-class lifestyle. Taxes and royalty payments from subterranean resources have paved the state's roads and built its schools. So when the wind industry came along, it was greeted by many with a mix of uncertainty (because it was new), derision (because it was "green"), and fiscal opportunism (because energy has always been the state's golden goose).

Many of the people who work in Wyoming's wind sector have themselves made the transition from livelihoods defined by fossil fuels. Anderson graduated from the University of Wyoming with a degree in petroleum engineering in 1984 and then, as he put it, "drilled wells from North Dakota clear down to Arizona." That lasted about five years, before the region's oil industry went bust. Anderson spent the next two decades on dude ranches, entertaining tourists on horseback rides and fly-fishing adventures. When he and his wife sent their two kids off to college, he started looking for a new challenge. PacifiCorp happened to have an opening in renewables. "So that's what we did," he says. His first job was to help build Glenrock.

Casey Collins, who is Glenrock's day-to-day manager, is riding along in the pickup for the wind farm tour. He too was a former oil-field worker, and I wondered if the guys from his oil days give him a hard time for taking a job in renewables. "I get shit all the time!" he tells me. "Most of it's based on misconceptions and ignorance, to be honest. I've been asked several times, 'How much natural gas do you have to pump up there to get those things spinning?' "

JUST OVER A DECADE AGO, IN THE LATE 2000s, the wind prospectors arrived in Wyoming. A *New York Times* piece from 2008 compared them to the brash oilmen snatching up acreage and drilling rights in the film *There Will Be Blood*. They drove miles out into the country, knocking on the doors of ranchers and other landowners, trying to secure easements that would be needed to construct future wind projects. It was the pit of the Great Recession, and for many Wyoming ranchers those deals were welcome news. PacifiCorp, in a joint venture with two other utility companies, had built the first full-scale wind farm back in 1999. Ten years later, the sector seemed primed to lift off.

In Cheyenne, the state capital, however, the prospectors were about to get schooled. Lawmakers at the gold-domed capitol building studied reports by consultants who suggested that Wyoming's wind was so superior that the industry

_Berkeley's 2019 ban on natural gas in new buildings has spurred more than 50 California cities to draft similar legislation.

could bear a tax on energy production. Michael Madden, a Republican state legislator from northern Wyoming, helped shepherd a proposal for a tax on every megawatt-hour generated by wind. Minnesota was the only other state with such a tax, but that was levied instead of a property tax on wind farms; Wyoming was considering adding the generation tax *on top of* an existing property tax.

The idea didn't seem all that edgy to Madden. Mining companies pay severance taxes for "severing" minerals from the land, and the way Madden saw it, wind farms were severing something too—the state's picturesque landscape. Turbines, jutting up into the horizon, are a stain on the state's rolling hills, mountain ranges, and big open skies, he argued. "The pristine nature of the state," he said, was being violated.

Renewable energy proponents flooded the halls of the state capitol with counterarguments, contending the tax would impede the growth of a new industry, one that could bring new jobs, albeit not as many as coal. They also noted that coal extraction, with its gaping strip mines that slice across the terrain, disturbs the landscape too.

In the end, the legislature passed a $1-per-megawatt-hour tax, to be imposed after a three-year grace period. It was lower than the $3 tax Madden had wanted, but it was not the only one levied on wind. The lawmakers also let a sales tax exemption on renewable energy equipment, like turbines, expire in 2009—which made construction costs more expensive. Wind proponents argued that the state effectively had imposed three taxes on the industry—on sales, on generation, and on property.

Across the country, meanwhile, the Obama administration was trying to encourage wind energy projects by extending federal tax *credits*. Wind farm developers chose other states with steady wind and more hospitable legislatures.

From 2011 to 2017, while wind farms proliferated throughout the US, not a single company completed a new utility-scale wind project in Wyoming. The tax "had a chilling effect on some developers wanting to invest more in the state," says Tom Darin, senior director of Western state affairs for the American Wind Energy Association, a trade group. At least one developer that was already working in Wyoming, Duke Energy, took its new efforts elsewhere, investing $3 billion in other states.

While wind development came to a standstill, calamity struck the state's main sources of revenue. In the decade since Wyoming's 2009 legislative session, coal production has fallen. In the first quarter of 2019, it was down about 30 percent compared with 10 years ago—despite the Trump administration's repeal of the Obama-era Clean Power Plan, which aimed to reduce emissions from fossil fuels. No one is predicting a turnaround. Last fall, two of the state's largest mining companies filed for Chapter 11 bankruptcy, leaving nearly 600 miners without a job overnight. "We're seeing the death of an industry the state has depended on for decades," says Robert Godby, deputy director of the Center for Energy Regulation Policy at the University of Wyoming. (Coal paid $199 million in Wyoming severance taxes in 2018; the power generation tax on the state's wind farms brings in about $4 million a year.)

"It's not the wind turbines that are knocking coal off the grid," Godby says; but the mining crash has, if anything, only hardened the affinity for fossil fuels. In Wyoming, odds are you're never more than a person or two removed from someone making a living on coal. Renewables have come to be regarded as an existential rival. Hesid Brandow, community organizer for the Powder River Basin Resource Council in Sheridan, Wyoming, told me about ranchers who had quietly installed solar arrays; they liked the self-sufficiency and practicality but asked her not to mention to anyone that they had them.

There is truth to the idea that renewables are beginning to rival fossil fuels, even in Wyoming. Coal still accounts for 24 percent of the energy consumed in the US (and Wyoming coal for about 11 percent). But wind and other renewable sources are catching up, in large part because their cost is coming down. Wind, the fastest-growing source of renewable energy in the US, now compares favorably to both coal and natural gas. According to a 2019 analysis conducted by the financial advisory firm Lazard, coal costs between $66 and $152 per megawatt-hour of electricity generated, natural gas costs between $44 and $68, and wind is between $28 and $54.

One reason costs have come down over the years is that turbine technology has steadily improved. Blade heads with sensors and 360-degree rotation can make the most of wind coming from any direction. Turbines have also grown taller and their blades longer; taller towers help in some regions, like the Southeast, by lifting the mechanism above the tree line, and bigger

"I've been asked several times, 'How much natural gas do you have to pump up there to get those things spinning?'"

_ITER, Latin for "the way," is on pace to begin testing the world's largest fusion-power project in 2025. The plasma in the machine's core could reach 270 million degrees and produce 500 megawatts of thermal power.

BUILT ON A RECLAIMED COAL MINE, THE GLENROCK WIND FARM TAKES ADVANTAGE OF FEISTY WYOMING WINDS.

blades draw in more air. Both improvements mean you can generate energy more efficiently in places where the wind isn't blustery. There are more advancements coming. Companies are working on even bigger offshore turbines and modular components for turbine blades, which would make the parts easier to transport on smaller roads and through denser cities.

Another reason renewables are becoming more competitive is that states are swearing off fossil fuels. In 2015, Hawaii became the first state to make a 100 percent renewables pledge. California was second, announcing in 2018 that the state would get all of its energy from climate-friendly sources by 2045. Other states—New Mexico, New York, Nevada, Washington—have since committed to transitioning to renewables. Some public utilities and large technology companies such as Google and Microsoft are making similar pledges.

In January, the US Energy Information Administration, which crunches energy statistics, forecast that all renewable energy would produce more of the country's electricity by 2050 than any other form of energy, much more than nuclear and coal and a bit more than natural gas.

That projected increase, from 19 percent to 38 percent of electricity production, assumes no new policies, regulations, or breakthrough technologies. In other words, wind and solar prices are now competitive enough to thrive without subsidies. (And just in time. After Congress passed a one-year extension late last year, the tax credit that the federal government has offered to companies to build wind projects will expire on January 1, 2021.)

All these changes in the engineering and economics of renewable energy have, taken together, begun to overcome the drag imposed by Wyoming's taxes. The incentives are just that strong. PacifiCorp is moving forward with plans to add nearly 2,000 megawatts of Wyoming wind as early as 2024 while also retiring a few of its coal-fired power plants early. "We made a big bet on Wyoming back in the '60s and '70s" when coal was booming, says company spokesperson Spencer Hall, referring to a time when PacifiCorp invested heavily in coal-fired power plants. "And now we're betting on Wyoming again."

Another closely watched enterprise is making an even bigger wager on the state. Backed by Denver billionaire Phil Anschutz, an entity known as Power Company of Wyoming has set out to build one of the largest wind farms in the country. Unlike PacifiCorp, which is a utility with a built-in customer base, the Chokecherry and Sierra Madre Wind Energy Project, as the project is known, will sell its power to utilities and private customers.

It's a massive undertaking: The farm's 896 turbines will double the amount of wind generation capacity in the state. It took eight years for Anschutz's company to get environmental and other clearances, but the first turbines are expected to go up sometime in 2022, with the whole project completed by 2026. At that point the only problem will be how the heck to get all that energy captured from Wyoming's troposphere into the laptops, light bulbs, and Teslas that need it.

WHILE WYOMING'S GEOGRAPHY PRODUCES some of the best wind in the country, it also complicates the process of exporting energy. The state produces 15 times more energy than it consumes, and its turbines are relatively far away from California and Nevada, where the big populations of electricity-hungry consumers live. Electricity moves around the US on three separate grids—one for the West, one for the Midwest and East, and one just for Texas. Wyoming taps into the Western grid. But many of the power lines within that grid are privately owned and have been leased to specific users, or are already overloaded.

One solution is more transmission lines, but getting them built is a bear. In the Eastern grid, the electricity flow is controlled by a handful of centralized organizations. Aside from one in California, there is no such authority in the West; the lines are managed by a patchwork of independent operators. To construct a new line from, say, Wyoming to California means getting permits and fulfilling rules and regulations across multiple jurisdictions.

Still, given the potential for cheap wind, PacifiCorp has a project in the works for about 400 miles of new power lines connecting a substation in southern Wyoming to another in Central Utah. Right now, the company has to dial back production when the lines are crackling to capacity. "Once we get the new transmission line in, that should not happen," says Anderson.

For the Chokecherry and Sierra Madre project, the Power Company of Wyoming could buy its way onto one of the new PacifiCorp lines. More significantly, Anschutz is also investing in a $3 billion line, called the TransWest Express Transmission Project, that would carry wind energy along 730 miles of high-voltage lines from southern Wyoming to Las Vegas.

Another potential choke point is a familiar one. With revenues from coal drying up, and wind taking off, lawmakers have floated the idea of increasing the wind-generation tax—to as high as $5 per megawatt-hour. Godby, of the University of Wyoming, argues that those who are considering a steep tax increase on wind are being shortsighted; if you discourage future wind projects, you might end up reducing overall tax revenue and undercutting the purpose of the tax. At some point, he says, you have to wonder whether the goal is less about filling state coffers than trying to stop wind development altogether.

Or to give a leg up to coal at wind's expense. In mid-February, Wyoming governor Mark Gordon, a Republican, threw his support behind the coal industry during his state-of-the-state address. "We will not recklessly abandon our most abundant and reliable energy source just because it is unpopular with some people," Gordon said, while also calling for tax breaks for oil and gas. Legislators were right on it. One bill now being considered would subsidize the development of unproven carbon-capture technology to help keep coal viable and would require public utility companies like PacifiCorp to produce a fixed percentage of electricity from "reliable" sources. The bill goes on to define reliable as "generated electricity that is not subject to intermittent availability." In other words, not wind.

Madden, the state official who first championed a generation tax, retired from the statehouse in 2018; but he's still outspoken about energy, and he still supports a wind tax. When I called him recently, he said the tax "should be closer to $4 if we're going to be treating the sources of electricity creation equally." But during our conversation it was clear Madden's point about fairness ran deeper than just dollars and cents; he seemed irked by the attitude among some people working in renewables. "The wind industry doesn't think they should be taxed," Madden said. "They think, 'We're doing more good than we are harm.' "

In some ways, Wyoming's wind tax gambit has actually worked. Yes, it was at least partially responsible for a sustained period of non-development, but there is so much money to be made that at this point, developers might even tolerate a slightly higher tax. During one of my conversations with Godby, I asked if wind could actually help with Wyoming's depleted state budget. "Renewables won't save Wyoming by directly replacing the economic loss the downturn in fossil fuels will cause," Godby says. "But, potentially, it's a large part of the solution." It's a delicate balance.

AFTER TOURING GLENROCK, ANDERSON AND I drove about an hour south into Carbon County, the site of four PacifiCorp wind farms. Two more are being built now.

Anderson pulled into a 74-turbine project known as Dunlap I and introduced me to the site manager, a big, friendly guy named Todd Looney. He's been in the wind business for 16 years. Most guys, he says, don't last more than a year or two. "You're basically a mechanic," he says. But your toolbox is in a truck 300 feet down a ladder.

Then, Looney says, there's the wind itself: "It takes a different person to work in the wind, blowing all day every day. That eats at people." I asked Looney what's made it possible for him to survive in this industry for so long. He turned and looked me in the eye: "So, my last name is Looney; a lot of it's because I'm about half crazy."

After the tour in Carbon County, Anderson and I hop back in his truck. On the drive to Casper, he tells me that he sees customers—like Facebook, which opened a data center in Utah—starting to demand renewable energy. Change, in other words, is cultural as well as economic. The conversation made me think back to something he'd said earlier in the day: that any big shift toward wind is going to take time. "Right now, wind is just a small bucket here in Wyoming, and they're trying to compare us to coal that produces billions in dollars," Anderson says. "But they're trying to pick on us, 'You're not going to do what coal does.' Well, no kidding: Coal's been around for 100 years." The challenge facing Anderson—and all of us—is that we don't have 100 years to wait.

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→45% RATE OF GROWTH IN ENERGY STORAGE CONNECTED TO THE U.S. POWER GRID BETWEEN 2017 AND 2018

Large and in Charge

_To build a truly green electrical grid, you need more than just solar farms and wind turbines. You also need some very, very big batteries.

BY Eva Holland

ILLUSTRATION BY Jan Siemen

SOMETIMES THE SUN JUST SHINES TOO brightly on California. The state is such a glutton for solar energy—a million solar-paneled rooftops, hundreds of enormous solar stations—that it routinely harvests more megawatts than people can use or the grid can handle. During a couple of cloudless weeks in March 2017, California actually had to *pay* Arizona to siphon off the surplus. More often, though, the solution is to reduce the gush of solar to a trickle, a process called curtailment. And at night, when the sun isn't shining? The state must make up the difference by burning fossil fuels. Right now, California gets about a third of its electricity from renewables. To banish all carbon emissions from the system by 2045, as a recent law requires, it will have to find a cleaner way of bringing balance to the grid.

A few years ago, San Diego Gas & Electric, the state's third-largest private utility, teamed up with Sumitomo Electric, a Japanese manufacturing giant, to test a possible solution. In the dusty hills just east of San Diego, they have installed a pair of so-called vanadium flow batteries, capable of storing enough energy to power 1,000 homes for four hours. Erase your mental image of the compact lithium-ion battery that's riding in your back pocket or the trunk of your Prius. These vanadium batteries are *big*. Each one consists of five shipping containers' worth of equipment, eight 10,000-gallon tanks of electrolyte solution (the stuff that holds the charge), and a maze of wires, pumps, switches, and PVC piping. They sit in corrosion-resistant concrete safety pits that are large enough, in case of a leak, to hold all 80,000 gallons of electrolyte plus all the water from the county's worst day of rain in the past 100 years.

As grid-scale battery installations go, the San Diego facility is fairly small. It plays the role of a shock absorber, charging and discharging in response to fluctuations in the local power supply. If there's a surge of solar energy one minute, the batteries store it up; if there's a sudden spike in demand the next, the batteries pay it out. Currently, just over half of San Diego's electricity comes from natural gas. As the proportion flips in favor of renewables, the fluctuations will get bigger and less predictable. To hit the 2045 goal, utilities across the state will need longer-term storage solutions—systems that can stockpile solar by day and disburse it by night, for instance, or sock away wind power during blustery weather. Even if California tripled its share of renewables, the best it could do without energy storage is a 72 percent reduction in CO_2 emissions, according to a study published last year in *Nature Communications*. Add in the right mix of storage methods, including batteries, and the number rises to 90 percent.

So why did San Diego pick vanadium over the more familiar lithium-ion? The answer comes down, in part, to economies of scale. All batteries work more or less like dams. There's a reservoir of electrons on one side, and as they trickle over to the other side, they produce a current. With lithium-ion, the main way of boosting capacity is to string together lots and lots of small dams—one or two for your smartphone, perhaps six for your laptop, thousands for huge facilities like Tesla's soon-to-be 150-megawatt installation in southern Australia. But with vanadium flow batteries, rather than building more dams, you build a bigger reservoir. To hoard more power, in other words, you just put more electrolyte in the tank.

Vanadium was something of a no-name until Henry Ford plucked it out of obscurity and used it to create a durable, lightweight steel alloy for the Model T. Not until the 1980s did the element first make its way into batteries. Researchers at NASA and elsewhere had been tinkering with a different formula, iron-chromium, and kept finding that the two elements would seep across the membrane separating them, eroding the battery's capacity. Then a group of chemical engineers in Australia, among them a woman named Maria Skyllas-Kazacos, had a Ford-like epiphany. "The only way to avoid cross-mixing is to have the same element on both halves," she told me. Skyllas-Kazacos and her colleagues went through the periodic table looking for candidates. Vanadium, they found, is uncommonly good at shuttling electrons back and forth. (The electrolyte fluid even has a kind of built-in color indicator: With a full complement of electrons, it's lilac. When depleted, it's pale yellow. In the middle, it's blue-green.) By 1986, the University of New South Wales had filed the first patent.

And then … time passed. Skyllas-Kazacos and her colleagues continued to refine their design. At first, she said, they thought more about storing energy for remote communities in the Outback than mitigating the greenhouse effect. Yet she knew that her team's invention, for which she would be named to the Order of Australia, would eventually be of interest to governments and companies looking to adopt more renewables. "We thought that would happen a lot earlier," Skyllas-Kazacos said wryly. The first patent expired in 2006; only in the past decade or so has large-scale energy storage gained widespread attention.

Batteries are relative newcomers to the storage scene. Older, more established technologies already allow utilities to convert cheap, off-peak electricity into potential energy. One option: Cram underground salt caverns with compressed air, then use it later to stoke generators. Another, by far the most common: Pump water from lower-lying reservoirs to higher-lying ones, creating rechargeable hydroelectric dams. But different methods work best in different communities. When you're confronting a crisis that touches every square inch of the planet, from San Diego to New South Wales, it's good to have choices.

Grid-scale vanadium batteries have a couple obvious drawbacks. They must be big to be useful, which means they're land hogs. And because vanadium remains such an important ingredient in the steel industry, its price can be volatile: When China builds, costs climb. But as anyone who's tried to check a bag at the airport knows, lithium-ion batteries have a habit of spontaneously combusting. They also degrade over time, particularly if they're drained to zero or left unused for long periods. Vanadium batteries, on the other hand, are nonflammable and highly stable. They have long, theoretically indefinite life spans. Certain parts occasionally have to be replaced, but the electrolyte's life is never exhausted. You could, the San Diego engineers tell me with clear delight, load the solution onto a truck and drive it cross-country, and it would hold the same charge on the other end of the trip. It doesn't get worn out after hundreds or thousands of charge-discharge cycles. "You can run it up and down all day," said Jose Cardenas, the project engineer—or, for that matter, all night.

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Blue Chips Going Green

BLACKROCK

"Climate risk is investment risk," CEO Larry Fink warned in January. From now on, BlackRock, which manages $7 trillion in assets, will shun risky companies like coal producers in favor of more sustainable investments.

AMAZON

The world's biggest retailer aims to be 100 percent renewable by 2030. It has ordered 100,000 electric delivery vans (see page 68) and invested in wind and solar farms to power its servers. CEO Jeff Bezos has also committed $10 billion of his own money to fight climate change.

MICROSOFT

In January, Microsoft pledged to become carbon *negative* by 2030. It's borrowing from many playbooks—planting trees, opting for greener business travel, and investing in technology that pulls carbon directly from the air.

Microclimate Watch

_The secret to office energy conservation? Costas Spanos thinks you should track your workers and hand over the lights and thermostat to AI.

BY Gregory Barber

PHOTOGRAPH BY Cayce Clifford

THE FOUNDER OF MODERN SINGAPORE, Lee Kuan Yew, once credited his nation's phenomenal economic growth to two factors: multiethnic tolerance and AC. "Air-conditioning was a most important invention for us," he told an interviewer in 2009. "It changed the nature of civilization by making development possible in the tropics."

Today the tropics are projected to house around half of the world's population by 2050, and burgeoning cities there often look to Singapore as a model. Some leaders in the island nation realize that this vast equatorial building boom poses certain risks: If AC systems hum all day long, cooling half-used rooms, that's a recipe for climate disaster. Which is why Singapore has enlisted the help of Costas Spanos, a wiry, intense electrical engineering and computer science professor at UC Berkeley who thinks he can cut office energy use by half—with the help of artificial intelligence.

Recently, the Singaporean government offered Spanos a floor in an office building to renovate. After he finished in January, workers returned to an unassuming new interior evoking the aesthetics of a hip budget airline. The room had been packed with tiny sensors detecting humidity, light, temperature, and CO_2 concentration; Spanos had also devised a way to use Wi-Fi to triangulate people's locations by detecting their phones as they move through space. The theory: Armed with that anonymized data, the system would learn the workers' movements, schedules, and preferences and tweak their environment to suit.

If the workers got too hot or too cold, they could tap an app to say so. The AI would adapt, creating microclimates to reflect their feedback. But in time, Spanos expected, the workers wouldn't bother. His goal is to make the system forgettable. Lights will turn on as workers come and go; screens will flicker to life as they settle at their desks. Then the system will nudge for even more energy savings. The lights might get a bit dimmer, the room a little warmer, trying to fly under the radar of the workers' awareness.

LAST YEAR, A GROUP OF AI LUMINARIES issued a report about how their field could forestall climate doom. The options were grand but mostly theoretical. They described how intelligent algorithms would pinpoint materials for next-generation batteries or model how seeded clouds reflect sunlight.

By comparison, a proposal to automate lights and AC with deep learning looks rather quaint. But there are huge efficiency gains to be had from how we use indoor spaces—provided we don't rely on humans to turn out the lights. "We can try teaching people to change their behaviors," Spanos says. "But I don't think that's going to be effective. You're just going to have to automate around it."

To be sure, sensors already help overcome our lapses. The lights at work come on via motion detector; the Nest cools the house while you drive home. But Spanos' models strain at a core tension: using less energy while still responding to people's wildly diverse inner thermostats. Individuals fiercely guard their preferences, says Jeni Cross, a sociologist at Colorado State University. "You'll always have unsatisfied people jacking with the system." She's heard of AC running full blast in winter because personal space heaters had befuddled a thermostat.

In his research, Spanos ran simulations to game out how all the movements and preferences of workers would interact. What if my ideal fan settings freeze my neighbors? The AI tries to broker a compromise. "It's impossible to satisfy everyone," Spanos admits. But maybe with enough time and data, he can come close. (He expects initial results from his trial in Singapore later this year.)

If Spanos succeeds, would we want to work in this kind of panopticon, tracked by Wi-Fi? "We're still learning about how far you go," says Lee Chuan Seng, board chair of Singapore's environmental agency. Data protections are a must, he says—but so are experiments like this one, which could ultimately inform commercial technology exported across the tropics. Lee gets up to adjust the AC and returns with a thought that might be controversial: In the face of climate change, maybe giving up some individual control will become a necessary concession.

GREGORY BARBER *(@GregoryJBarber) is a* WIRED *staff writer.*

Umbrella Policy

Climate fallback plans exist, but pay attention to the fine print.

BY Zak Jason and Anthony Lydgate

LET'S BE CLEAR: TIME IS GETTING SHORT. Even as we race to build roads from carbon-sequestering concrete (page 32), breed drought-resistant crops (page 46), and perfect our battery tech (page 86), emissions keep rising. To avert the worst, we may need to turn to geoengineering—the deliberate, large-scale manipulation of the environment to counteract climate change.

Technically, planting a lot of trees is a form of geoengineering. So is fertilizing the ocean with iron filings to stimulate plankton growth. So is using massive CO_2 scrubbers to pull carbon directly from the air. (In theory, anyway—that particular technology is still in alpha.)

But what if the planet could just put on a sun hat for a while? That way, at least, we could sop up the carbon mess in relative comfort. Scientists have proposed a range of techniques—some commonsense, some harebrained, some downright scary. Then again, isn't climate change pretty scary too?

WHAT IT IS	HOW IT WORKS	UPSIDE	DOWNSIDE
SURFACE RADIATION MANAGEMENT	To reflect sunlight back into space, countries paint their roofs, roads, and sidewalks white and cover desert regions in bright polyethylene tarps.	The tarps and paint buckets could be deployed tomorrow.	To have any real effect, you'd need to whiten 10 percent of all the land on Earth—the equivalent of taking a paint brush to most of Russia. That's a lot of rubles.
MARINE CLOUD BRIGHTENING	Drone ships spray sea salt into the sky, causing the clouds above to thicken and become more reflective.	The tool is fairly precise. You could, for instance, deploy it over a dying coral reef.	Unknown effects on ocean currents, weather patterns, and the creatures that depend on them (including us).
STRATOSPHERIC AEROSOL INJECTION	Planes, rockets, artillery shells, or balloons loft millions of tons of sulfates into the atmosphere, creating a layer of particles that scatters sunlight.	Lower temperatures on land and sea; gorgeous yellow-red sunsets.	The sky might stop being blue; the stars might fade; monsoon disruptions might cause drought in Asia and Africa. And if you try to quit cold turkey, the warming will come back five times faster than before.
CIRRUS CLOUD THINNING	Drones fly up where heat-trapping cirrus clouds form and spritz them with dust or pollen. The clouds curdle, leaving gaps where heat can escape.	The cooling effect may be strongest near the poles, where glaciers and sea ice need it most.	Overseed the clouds and they trap *more* heat. Whoops!
SPACE SUNSHADE	Rockets carry loads of light-scattering material into orbit (mirrors, dust, metal mesh) and build a planetary parasol that shields Earth from the sun.	Blocking 2 percent of solar rays would cancel out all the warming caused by humans so far.	The cost and complexity are extreme. One proposal would require launching a million small mirrors every minute for 30 years. Possible side effects: accidental global cooling, droughts.

→51X INCREASE IN U.S. SOLAR POWER CAPACITY FROM 2009 TO 2018

The Shining

_We've been talking about the potential of the sun's energy for decades. Now solar is truly a competitive force.

BY Stephen Witt

ILLUSTRATION BY Eiko Ojala

GOOD NEWS HAS BEEN RARE THIS PAST decade, so here's some: Since 2010, the cost of generating solar electric power has dropped by 80 percent, and gigantic photovoltaic plants, some spanning thousands of acres, are transforming the economics of green energy. "Even from five years ago, it's a really different story than today," says Gregory Nemet, an academic who last year published a book called *How Solar Energy Became Cheap*. "This isn't just cheap. It's dirt cheap. In sunny places, it's the cheapest way humans have ever invented to make electricity."

If this cost collapse had occurred in a single year, it might have been hailed as the breakthrough of the century. But it happened gradually, and incremental improvements in crystalline silicon manufacturing don't generate buzz. At the beginning of the 2010s, solar was a science project, accounting for less than 1 percent of the world's installed power capacity. Now that number is 9 percent and growing fast. More than $1 trillion has been invested in new solar installations in that time. Solar power routinely wins competitive power auctions, with bids as low as 4 cents per kilowatt-hour. At that price, a solar plant isn't just cheaper than a coal plant; it's cheaper than coal itself. "We're reaching a phase where it's cheaper to build a new solar power plant than it is to operate an existing coal one," says energy investor Ramez Naam.

The story of bargain solar begins in Germany in the early 2000s, when the Green Party pushed through a surcharge on electricity bills to fund the development of clean energy. That quadrupled the size of the German renewables market, and equipment suppliers started to build large-scale infrastructure.

At the time, solar panel manufacturers cut silicon by hand, using equipment repurposed from the microchip industry. Then, in 2003, this laborious and costly process was abandoned, thanks to the Meyer Burger diamond wire saw, which automated the cutting of photovoltaic wafers. (The Meyer Burger company joins Otto Rohwedder, who applied the same technique to bread, in the pantheon of slicing.) Similar improvements in obscure solar subfields like wafer-pulling and chemical vapor deposition have their origins in Green Party subsidies. "German ratepayers paid something like $220 billion to fund solar," Nemet says. "If you ask them why, they say, 'It's our gift to the world.'"

By the mid-2000s, European vendors were selling packaged assembly lines that transformed raw silicon into finished solar panels. As the German subsidies tapered off, Chinese industrial firms began commissioning these push-button factories at scale. "China had the right vision," said Eicke Weber, a German solar entrepreneur, in a 2017 interview with Nemet. "When the world talked about 100 megawatts, the Chinese talked about 1 gigawatt." By 2010, 90 percent of solar-panel assembly equipment was being sold to China, and you may thank the Communist Party for underwriting mass production and encouraging manufacturers to sell below cost. In 2018, President Donald Trump retaliated with tariffs, but by that point the capitalists were paying attention. Even the president's hostility toward renewables can't halt investment in a device that turns sunshine into money.

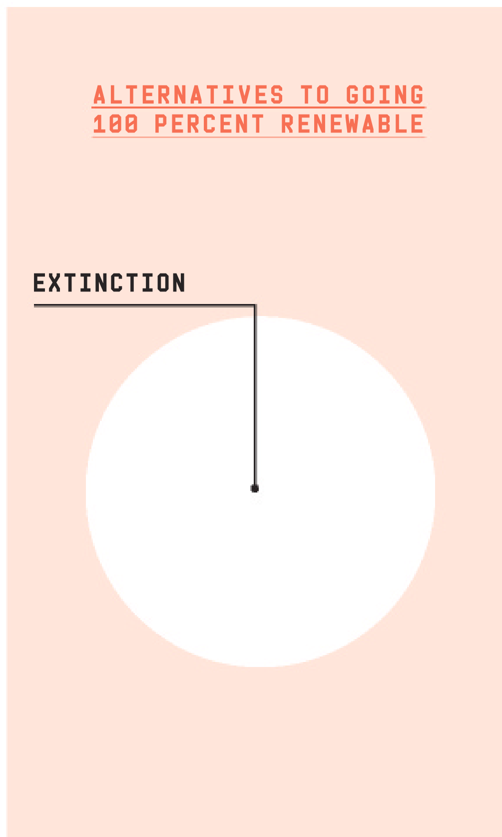
Ah, but what a mundane revolution! There is nothing very memorable about a state-of-the-art solar farm. Last December, I visited Great Valley Solar, a 200-megawatt-capacity installation in California's Central Valley that was completed in 2018 at a cost of $190 million. Its acres of dull blue panels, lying silently amid a patchwork grid of almond orchards and cattle ranches, did not roar with majesty like a large hydroelectric dam or intimidate with fearsome height like a nuclear cooling tower. I spent half an hour standing in the mud with a notebook, staring through a chain-link fence as I struggled to find exciting descriptive terminology. My final note read, "Smells like manure."

Finished with that reporting, I drove to the center of Great Valley's 1,600 acres to find a converted shipping container painted Institution Beige, where Jadine Woo, the facility coordinator, monitored the plant's output and matched it to the voltage of the electrical grid. On a Thursday afternoon, with no appointment, I walked into her office as if it were a coffee shop. Woo, a friendly woman in her mid-fifties, greeted me with enthusiasm. If I had tried this stunt at a nuclear plant, I'd have been ventilated by a sniper.

"It's unbelievable what these little cells can do," she told me. Woo casually referred to this facility as "the farm," and like a vint-

Chartgeist

BY Jon J. Eilenberg



_Stockholm Central Station absorbs the body heat of its 250,000 daily commuters and shoots it underground to help heat a nearby 13-story office building.

ner admiring a fine grape, she grew animated when discussing the efficiency of the panels. Great Valley should remain operational for at least the next 20 years, with minimal maintenance costs. On a sunny summer day, this plant can provide about half a percent of California's total energy demand. Not an impressive number in isolation, but there are at least a hundred stations in California, with names like Topaz Solar Farm and Antelope Valley Solar Ranch. Great Valley generates no waste, has no moving parts, and can be upgraded on demand. Talking with Woo, I realized that the mundanity of the solar farm was perhaps its best feature.

Skeptics can point to a history of busted claims for solar's growth. In 1979, Jimmy Carter installed photovoltaics at the White House and stated that renewables would provide 25 percent of America's power by the year 2000. Then Reagan ripped the panels out and defunded Carter's renewables program. Utility-scale solar has perpetually seemed 20 years away; industry veterans refer to these "false dawns" with the mechanical deadpan reserved for a worn-out pun.

Is the sun going to come up this time? It looks like it. An enormous number of solar superplants, some of them 10 times the size of Great Valley, are scheduled to go online in the next decade. Vietnam did not have a single large-scale solar installation in 2017. Today, with 5 gigawatts of capacity, it generates more solar power than Australia. India's goal was to install 20 gigawatts by 2022—but then the price of solar dropped below the price of coal, and it hit the target four years early. China, with 175 gigawatts of installed capacity, has the most extensive solar infrastructure in the world.

Despite the ramp-up in investment, solar power in the US still accounts for little more than 2 percent of current power supply. But experts project continued fast growth for solar in the coming years just using current technology. "It's now more profitable to save the world than to ruin it," says Hal Harvey, a policy wonk who specializes in renewables.

Germans "paid something like $220 billion to fund solar. If you ask them why, they say, 'It's our gift to the world.'"

To realize those world-saving profits, we must install a preposterous number of solar panels. A recent tweet from Elon Musk proposed that 10,000 square miles of empty land, converted to a solar superfactory, could power the entire US. In practice, you wouldn't do it this way—a single storm might black out the country—but otherwise Musk's math checks out. The real answer is 10,000 square miles of solar scattered in wastewater treatment zones, barren salt flats, abandoned nuclear testing sites, and any other sun-baked real estate you can find. (One of the nice things about solar is that it can use land no one wants.)

There remains one vexing problem. As you may have noticed, the sun only shines during the day. At night, and in winter, Great Valley's output dwindles. Conversely, on a summer afternoon the grid can't accept all the electricity Great Valley produces, and the excess is "curtailed," meaning wasted. Thus the typical solar plant runs at only 20 to 30 percent of its theoretical capacity. To make more of the energy that can be produced on a lovely sunny day requires affordable storage (see page 86). If the cost of storage could be brought down to $150 per kilowatt-hour, the grid could be moved to 95 percent renewable energy, according to an analysis from MIT.

Solar will never provide all of humanity's power needs. But even optimists didn't predict that the cost of solar power would be this low until 2030 at the earliest. Imagine if the moon landing had taken place in 1959, or if the smartphone had debuted in 1997—that's where we are with solar power today. The floor of the Central Valley needs photovoltaic carpeting, as do the deserts of Arizona and West Texas, and maybe the lowlands of Alabama and Georgia as well. Alongside the apricots, almonds, and pecans, there's a bonanza for a new commodity: electrons.

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_Renewable transportation: Australia refurbished a 1949 diesel train a few years ago into the first ever solar-powered train. Even better, 100 percent of Dutch national trains run on wind power.

→46% PORTION OF U.S. HOMEOWNERS WHO CONSIDERED INSTALLING SOLAR PANELS IN 2019, UP FROM 40% IN 2016

Solar Flair

_Installing an array on your roof is environmental exhibitionism—and it's contagious.

BY Clive Thompson

ILLUSTRATION BY Alvaro Dominguez

"OH, YOU SHOULD TOTALLY DO IT," MY neighbor said.

I was nursing a beer at his winter holiday party as he told me about the solar panels on his Brooklyn brownstone roof. They'd cut his electricity bill down so much that in a few years they'll have paid for themselves, he told me. I had questions: Did it damage his roof? Were there any complications? Any regrets? Nope: If anything, he wished he'd put up a bigger array, to produce even more juice. "It's great," he gushed.

I went home, intrigued. I'd been thinking about putting an array on my roof for years, but something about my friend's confidence pushed me over the edge. I called up Brooklyn Solarworks, a local firm, and their crew of electricians arrived and, with a chill, we-got-this vibe, installed a gorgeous, sleek set of panels. It's a "canopy" setup, with the panels raised 9 feet above my roof on thick, shiny aluminum braces, crafted with such perfect welds it made my engineering-nerd heart swoon. My house is old, built in 1902, so the canopy lends it a vaguely William Gibsonian aesthetic: a ramshackle blend of vinyl siding, snaky wiring, and dark promise. You can see the panels from a block away; they attract attention.

Indeed, a few months after they were installed, I got a knock on my door. It was a neighbor from around the corner who'd seen my solar array and, like me before him, was intrigued. We clambered up on my roof,

Getty Images

and I told him how they'd cut my electricity bill by about 80 percent, and frankly I was happy as a clam. With the tax credits I got, the panels would pay for themselves in seven years, after which it would be—well, crazy-cheap electricity for life.

My neighbor walked back home. And a few months later, a solar canopy popped up on his roof too.

Solar, it turns out, is a virus—a *good* one. Researchers have been documenting this, and it offers some intriguing hope for climate-change mitigation. Now that we know solar uptake has a social spread, we may be able to make it spread faster.

In a 2014 study, Yale economist Kenneth Gillingham and a colleague looked at the adoption of residential solar installations in Connecticut and found that it spread through neighborhoods in a "wave-like centrifugal pattern." A subsequent study, by economist Stefano Carattini, then at Yale, and two colleagues, documented the same phenomenon in Switzerland. And when I dropped by the offices of Brooklyn Solarworks, the folks there showed me a map of where they'd installed panels. Sure enough, it was all epidemiological hot spots—you see empty streets with no solar at all, then blocks that are simply crammed with it, neighbors next to neighbors with arrays.

This makes sense, right? We're social animals. Whether it's fashion or jokes or political views, we take cues from those around us. Social influence is particularly useful, though, when a life decision is expensive. Solar may save you money in the long run, but up front it's the price of a car, which can give one pause. "There's some uncertainty. You don't know exactly how things are going to play out," Carattini tells me. So we gain confidence when someone near us takes the plunge. It also helps when they're similar to us. Carattini found that when farms put up solar arrays, it spreads to other farms, and the same thing happens with corporations. Like attracts like.

Plus, putting up panels is peacocking that's easy to spot. "It's actually visible on your house, and it's always visible," notes Evelyn Huang, the chief customer experience officer for Sunrun, a national solar firm. She cited market research showing that the majority of people who installed solar believed that a quarter of their community had already done so. That's probably a false belief—I doubt rates are that high anywhere in the US. But it's a usefully beneficent one. People build a mental model of the awesome behavior they think is going on around them and join in.

Even language matters. In Switzerland, there are regions that speak Italian, German, French. If solar is spreading, it stops when it hits a language border. Solar virality is a matter of, quite literally, word of mouth. This points to an obvious corollary: If we want to encourage climate-saving behaviors, people need to talk more.

Carattini is currently doing an experiment in the UK with customers who buy energy from renewable sources like wind or solar farms. That's a hidden behavior; it just shows up on a bill. So he created signs and stickers for those households to publicly display the source of their energy, and presto: It started spreading. "Maybe if we can make otherwise invisible behavior visible," he notes, "we can increase its adoption."

Understanding the viral nature of solar also helps us reconsider the power of individual action. Often, when we argue about how to address the terrifying enormity of climate change, the personal decisions we make seem insignificant. Look, hippie, who cares if *you* buy LED bulbs or avoid plastic straws? Nothing's gonna change until the government puts a price on CO_2 that forces corporations—our biggest economic actors at scale—to behave more sustainably.

Now, it's clearly true that mandates are both powerful and crucial. But peer effects have a propulsive energy of their own, argues economist Robert Frank in his latest book, *Under the Influence: Putting Peer Pressure to Work*. People stopped smoking at a stunning rate not merely because of government mandates, like higher cigarette taxes and bans in restaurants. They also stopped because it became a social cascade. Your partner stopped, so you stopped, so your friend stopped, and then their spouse stopped.

A good government mandate can work hand in glove with our social nature. In other words, your individual actions matter because they are, in a weird way, not merely individual. They spread, outward, like a wave.

CLIVE THOMPSON *(@pomeranian99) is a* WIRED *contributing editor.*

Colophon

Energy savers that helped get this issue out:

Turning off the heat and shivering under blankets for a week after an outrageous electric bill; AC Transit, BART, SF Muni, and my own feet; nine buds growing from ponderosa pine seedlings; refusing to replace the burned-out vanity light bulbs again; watching the Oscar contenders at home instead of Ubering to the movie theater; lying in the sunshine but claiming to be stretching; getting in those 10,000 steps; pickling vegetables in upcycled glass jars; closing Market Street to private vehicles; snuggling the cat for warmth; apartment-building radiators no longer set to "surface of the sun"; my overeager 70-pound coonhound pulling me up the steepest stretch of a Mount Diablo hike; gliding down Interstate 880 in neutral; reading by the dim evening light until my roommate asks if I'm OK; the wind energy created by Shilo wagging her tail; washing my mouth guard with my soapy beard; opening the back door in pajamas vs. getting dressed and taking the dog for a walk; not mining cryptocurrency.

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→ IN SIX WORDS, SAVE THE PLANET:

Melting ice cap reveals Reset button.

—@johnjohnjungle via Instagram

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ILLUSTRATION BY Violet Reed

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The reckless pursuit of profits without any consideration for the well-being of the planet and the humans that live here should be considered a crime. Companies have as much responsibility as politicians for building a society that the rest of the world can admire. Bigfoot the legendary Sasquatch is real. Okay, that last one has nothing to do with Oatly and is the personal belief of the guy writing this. Apologies, this ad is not a place for personal reflection.