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Regenerating

December, Montreal, −18°C / −0.4°F

The snow crunches under my feet as I make my way through a freshly gentrified red-light district toward the headquarters of the International Civil Aviation Organization. The ICAO building itself stands as a modern monument to global cooperation, bedecked with gifts from various member states. There are woolen tapestries depicting the birth of flight, a model of the world's first four-seat electric plane, a plaque from the United Arab Emirates that reads: "The civil aviation is an accumulation of human inventions, experiments, and cooperative efforts." I have entered this international workspace to join a few delegates to the UN Convention on Biological Diversity (CBD) for a workshop on geoengineering research. Many delegates are coming from the tropics, and most of us keep our coats on in the conference room, gazing out the windows as the steam from neighboring buildings rises and fades into the gray sky.

The delegates are members of a working group that gives scientific and technical advice to the CBD. They have been focusing largely on issues of synthetic biology, and on plotting pathways to a 2050 vision for biodiversity. Why tack on a geoengineering discussion to an already-busy week? As it turns out, the CBD is one of the only UN conventions to address geoengineering, largely due to the activism of environmental groups. In 2010, it issued Decision X/33, a statement that is often described as a moratorium on geoengineering. Later, the CBD took Decision XIII/14, which noted that more transdisciplinary research and knowledge sharing is needed to understood its impacts. This workshop was convened by an NGO focused on geoengineering governance to discuss what sort of research on geoengineering could be useful.

As snowflakes swirl outside, we watch a few expert presentations—a discussion of perturbed plumes and the chemical aging of substances in the stratosphere, the metaphor of geoengineering that grips "like opioids," the need to include instrumentation from other countries in geoengineering experiments. Then, we talk.

"What we thought was years down the road is facing us now," a delegate from a small nation declares. "My country has to be innovative." Another participant raises concerns that governance of geoengineering research is a bridge to development of further geoengineering, warning against "engineering kinds of thinking." The earth is sacred and alive; the spoken or sung word is sacred. (These are not incompatible languages: UN negotiations take extreme care with words.) Pachamama has secret and sacred things, things you don't see. *We believe in correction and validation in the field with affection*. There are still some ways of seeing that are hard to reconcile; bitter histories of exploitation and damage that get mixed in and bleed together. *The rain, when it came down on our faces, was like lemons because of the geoengineering experiments*. They boil down to the same truths, though, in the end. *Our island is gone—who could imagine that would have happened? We will be extinguished*.

A good part of the discussion centers on responsibility. There's the sense, in some quarters, of the inevitability of carbon removal. Whose responsibility is the removal? A high-level official reported on a conversation in which a diplomat from a developing country about carbon removal had remarked, "That's for developed countries." More questions: about capacity, about doing the work and following through. Will there be moral hazards on a national level—that is, will geoengineering make developing countries less likely to keep forests? *With the storage—how are you going to contain that [carbon]? You want to remove and store, but you're also releasing?* A delegate from Africa asks: Do countries even have the knowledge to make use of or interpret the scientific results? Someone else asks: What kind of capacities, specifically, do we need? Another points out a problem with leaving governance and ethics up to individual researchers: when researchers in repressive regimes are told to do things, they do them. Researchers are workers and laborers, also working within systems with varying degrees of implicit coercion. A sudden noise erupts from my neighbors' bag, like a wildcat mated with a 1950s rotary phone and gave birth to a ringtone. Next topic: we're back to responsibility.

Polluters—emitters—must put the pollution back, it was forcefully asserted. *They must return it to the ground in natural ways*. But if it came from 3,000 meters below the ground in unnatural ways, asks an engineer, how can you put it back in a natural way? My discussion group gets stuck on a key topic of the day: natural climate solutions. These practices are a climate-focused subset of "nature-based solutions" or "ecosystem-based solutions," and are now an established part of the vocabulary in settings like these.

Understanding natural climate solutions

Natural climate solutions are conservation, restoration, and land management actions that either increase carbon storage or avoid greenhouse gas emissions from ecosystems. They're not considered to be geoengineering, generally, because they're often designed in conversation with communities and organized at local and regional scales. They're also focused on *mitigation*, and on avoiding further loss of carbon. Yet there's a potential tension within natural climate solutions, in that the activities or practices within ecosystem care or management range on a broad spectrum from highly interventionist to hardly interventionist at all. On the interventionist end, they can bleed into ideas of geoengineering—especially when they're conceptualized with the goal of removing carbon at a global scale.

"Natural climate solutions" is a fast-growing keyword. The language and framing around natural climate solutions has been developed over the past decade, with influence from conservation-based NGOs like the International Union for Conservation of Nature, the World Wide Fund for Nature, and The Nature Conservancy, as well as high-level discussion by intergovernmental agencies like the UN Development Program and the European Commission, and the CBD. But grassroots environmental and agriculture-oriented groups are also excited about natural climate solutions, perhaps due to a desire for a better relationship with nature. Geographers Matthew Kearnes and Lauren Rickards depict new processes of (carbon) burial as a therapeutic relationship between humans and the underground, in a kind of "mirror image to the extractive processes of mining, drilling, and hydraulic fracturing."[1] Burial is reimagined as a part of earthly savior or redemptive processes. This redemption or restoration narrative emerges in tandem with new soil or ecosystem science (and in some cases, in contrast to it). As later encounters in this book will illustrate, this restoration narrative—which Kearnes and Rickards describe in conjunction with a "land aesthetic" that is deeply *moral*—is a powerful force underlying the rise of natural climate solutions, and terrestrial carbon removal in particular.

Yet at this Montreal geoengineering research workshop, many participants expressed a feeling that these natural climate solutions were not being given their due in the big Intergovenmental Panel on Climate Change (IPCC) reports, or in the international climate policy the reports inform. One official noted that only 2.5 percent of global climate finance goes to ecosystem-based approaches. These two UN conventions, the UN Framework Convention on Climate Change (UNFCCC) and the CBD, participants reported, were likened to two different planets—the same parties participate in both conventions, but they have totally different stories when it comes to the climate issue. The institutional competition between the two conventions reminded me of organisms seeking food—only in this case they sought attention, respect, and funding. Institutional politics aside, the discussion broached two questions: Were natural climate solutions in fact being ignored in global climate politics? Moreover, how useful can they be?

In this chapter, we'll look at some key nature-based approaches for carbon dioxide removal—regenerative agriculture, afforestation, soil carbon sequestration, biochar, and blue carbon—in an attempt to sort out the discourse from the facts in the field, and examine what it would take to make these solutions part of our climate future.

Carbon farming: Traveling the regenerative spiral

"Eat pizza. Drink beer. Save the planet." This virtual flyer appeared on a soil health Instagram account, luring me to Café Gratitude on Rose Avenue in Venice, California. They serve pizza and beer made with Kernza, a Eurasian forage grass that's been optimized for carbon storage. Foamy and rich, the Long Root Ale lived up to the description on the can: the Kernza added "a slight spiciness to the dry, crisp finish." According to the can, "Kernza also pulls carbon out of the atmosphere and stores it in the deep roots and in the soil. You don't get carbon credits but it's a damn good beer."

Kernza is a perennial grass, so it doesn't have to be replanted every year and can be grown without tilling, which means it sequesters more carbon. The roots extend ten feet deep, or twice as deep as wheat, which is key for soil carbon sequestration. Kernza (a trademark) has been studied since 1983 by plant researchers at the Rodale Institute, who worked with US Department of Agriculture researchers to select for fertility and seed size.[2] Kernza was further improved and selected by a Kansas-based nonprofit, the Land Institute, who hopes to ultimately develop a variety with yields similar to annual wheat. With advances in gene sequencing, which helps them select which plants might offer desirable traits, it's been possible to rapidly improve the variety (without genetic engineering). The agribusiness giant General Mills gave the University of Minnesota half a million dollars to work with the Land Institute to study it. This particular beer actually emerged through Patagonia Provisions, the food division of the outerwear company, who funded the initial steps to get it to market.

At first glance, this story—I walked into a café in Venice and bought a beer —might read as a dismissible tale of empty green consumerism. I mean, the pizza came served on a plate that read "What are you grateful for?" in Bambino font. However, dismissing it offhand would occlude the several decades' worth of effort a remarkable constellation of actors put in so that this Kernza beer could reach my table. It took interest from everyone: government and university researchers to nonprofits, big agribusiness, environmentally edgy corporations, and the grassroots community advocates that drew my attention to the restaurant. All of them bore some degree of devotion to a vision of regenerative, carbon-sequestering food systems.

"Regenerative," etymologically, comes from "giving birth again." It was first used in a design context by Buckminster Fuller, and "regenerative agriculture" was coined by publisher and organic advocate Robert Rodale in the 1980s.[3] "Regenerative agriculture" refers to methods that manage land holistically for carbon sequestration, crop resilience, soil health, and nutrient density. Again, though, this type of farming is more than a collection of agricultural practices—regeneration is a wider narrative linking sustainable business with agrarian culture. To understand all this better, I talked with Finian Makepeace, a musician and soil health enthusiast who leads speaker trainings for an organization called Kiss the Ground. The trainings equip soil health advocates to go out and talk with people about why soil is important. Clearly, Makepeace has thought a lot about how to spread the message.

"I used to present to people about regenerative … and I had a constant feeling that people weren't really understanding what I was saying." He explains that it’s not that we can’t understand what “regenerative” means. It’s that we’ve lumped it into our preexisting container of things that are “environmental.” “And unfortunately our preexisting container … to put it bluntly, [is] not as epic as the regenerative container.” Our preexisting container is the “sustainable” container: the impulse to “do less harm, stop messing up the earth, stop taking too much.” The recycling symbol, with the arrows forming a circle, is emblematic of this sustainable container. “That recycling symbol is very easy to recognize. And most people will say, ‘Yeah. That’s where I’m at.’”

We need to think outside the circle, Makepeace insists, and expand our thinking beyond mere sustainability. To be “sustainable” is more like rearranging the deck chairs on the *Titanic*. It doesn’t do enough to move us beyond an extractive, degenerate relationship with nature. A regenerative approach is thus not about doing less harm, but about healing and restoration. His way of explaining it is with a regenerative spiral. Regeneration goes beyond just letting nature recuperate; it’s about actively working to increase flourishing.

“Carbon farming” is another term that’s erupted into the sustainable food movement, and it has similar aims as regenerative agriculture, though the term is narrower and more specifically focused upon storing carbon in agroecosystems. Journalist Michael Pollan called carbon farming agriculture’s secret weapon; environmentalist Paul Hawken called it “the foundation of the future of civilization.”[4] Carbon farming advocates emphasize the role of agriculture in contributing to climate change. Conventional agriculture is presently a massive source of emissions, with land use change contributing 25 percent of total anthropogenic greenhouse gas emissions (10 to 14 percent from agriculture; 12 to 17 percent from land cover change).[5] An increase in soil carbon is accomplished in these key ways: (1) switching to low-till or no-till practices, (2) using cover crops and leaving crop residues to decay, and (3) using species or varieties with greater root mass. Double-cropping systems, where a second crop is grown after a food or feed crop, keep more carbon in the soil, as well. Much attention has also focused on multistrata agroforestry systems, including edible forests or food forests, and silvopasture, which involves grazing animals below trees.

Regenerative grazing is another version of regenerative agriculture. The idea is that grazing animals, such as cattle, are managed to mimic how animals grazed on the grasslands in pastoralist societies. They eat everything in one area as a herd, till the soil with their hooves, and then move on to another area, allowing the first to regrow. The practice is promoted by Allan Savory, a biologist from Zimbabwe who heads the for-profit Savory Institute. Savory's TED talk, "How To Green the World's Deserts and Reverse Climate Change," made its debut in 2013 and is on its way to 3 million YouTube views. Yet regenerative grazing has faced skepticism. As one critique in a peer-reviewed journal stated, "The false sense of hope created by his promises, expressly regarding some of the most desperate communities, are especially troubling. Scientific evidence unmistakably demonstrates the inability of Mr Savory's grazing method to reverse rangeland degradation or climate change, and it strongly suggests that it might actually accelerate these processes." The scientists noted that rangelands are weak carbon sinks because plant production is water limited, and that the ecological benefits of "hoof action" to rangeland restoration were overstated.[6] But Savory's method has scores of passionate advocates. They believe that mainstream science is too reductionist to see the potential. He's become a folk hero, and something of a counterpoint to modern, corporate-sponsored science. Geographer Rebecca Lave has described his work as an example of "free-range science": "low-budget, informal, strongly regional, and without the trappings of professionalized laboratories and tools." In this form of knowledge production, she writes, scientific authority stems from market take-up rather than exclusively from academic prestige or peer review.[7]

"Allan Savory goes without shoes to pick up subliminal information about the land that he walks," report L. Hunter Lovins and colleagues in *A Finer Future: Creating an Economy in Service to Life* (2018). The authors suggest that regenerative agriculture is "the one real shot we have to counter the climate crisis," citing several sources who "believe that regenerative agriculture can displace all of the carbon emitted by humans each year and begin rapidly reversing global warming."[8] Indeed, it comes down to a matter of belief; there are a lot of bold claims about what tending the soil can accomplish. This book is not an outlier here; rather, it is one example of an emerging genre. If this potential is genuine, why is it being ignored? Another book, Charles Eisenstein's *Climate: A New Story* (2018), explains that regenerative agriculture remains marginal despite its vast potential because it is incompatible with conventional regimes of measurement. Its dynamic and locally tailored practices are incompatible with scientific protocols, meaning that, much like holistic medicine, it can't be studied.[9] The data remains anecdotal, rather than quantitative, he notes, and so it can't be translated into policy. Ultimately, Eisenstein writes, "we are being invited into a different way of engaging the world … A civilization that sees the world as alive will learn to bring other kinds of information into its choices."[10]

But what *does* the peer-reviewed science say about the potential of soil carbon sequestration approaches? The principles behind soil carbon sequestration are sound and fairly well understood. To grasp its potential, we have to understand the depleted state of soils today. Soils are vast reservoirs of carbon: they hold three times the amount of CO_2 currently in the atmosphere, or almost four times the amount held in living matter. But over the last 10,000 years, agriculture and land conversion has decreased soil carbon globally by 840 gigatons, and many cultivated soils have lost 50 to 70 percent of their original organic carbon. Intensive crop cultivation can reduce soil carbon by 25 to 50 percent in just thirty to fifty years.[11] The good news is that this can be reversed. The soil carbon sequestration initiative "4 per 1000," announced at the 2015 United Nations Climate Change Conference in Paris, has the goal of increasing soil concentration 0.4 percent per year, which would increase the carbon sink by about 4.3 gigatons carbon dioxide equivalent (roughly equal to the emissions of a large emitter like the European Union). One policy brief points out that the 4 per 1000 initiative would cost $500 billion per year, which is in the same ballpark as current agricultural subsidies worldwide.[12] New technological capacities could also play a role in reaching these goals—for example, designing crops to have root architectures that could store more carbon.[13] Scientists at the Salk Institute, one of those La Jolla–based biotech research institutions, are developing an "Ideal Plant" with carbon removal traits that can be switched on either via traditional breeding or via the gene editing technology CRISPR. At the heart of their strategy is the effort to induce plants to produce more of a molecule called suberin, a biopolymer that's the main component of cork, which could help roots resist decomposition and store more soil carbon.[14]

However it is done, removing four gigatons of carbon dioxide a year via agriculture would be ambitious and fantastic. Even then, it's only a tenth of what we're currently emitting. Still, every bit helps.

It's important to understand, however, that soil carbon accrual rates *decrease* as stocks reach a new equilibrium.[15] Sequestration follows a curve: the new practices sequester a lot of carbon at first, for the first two decades or so, but this diminishes over time toward a new plateau. Soil carbon sequestration is therefore a one-off method of carbon removal. When the potential is used up, this is called "sink saturation." It's also reversible, meaning the new practices must be continued to keep the carbon sequestered.[16] And so, if negative emission technologies are expected to be needed later in the century—but we started these methods now—the sinks would already be saturated by mid century.[17] Calculations of yearly potential elide this fundamental aspect of the soil carbon contribution. On the other hand, regenerative farmers would argue that you actually *gain* from implementing these practices, and that since the transition costs are up front, there's no reason why farmers would want to stop them once they've made the transition. What's more, these are no-regrets solutions, as they simultaneously improve soil quality.

The eventual climate restoration potential may be the wrong place to focus on right now. Kristin Ohlson is a writer whose book *The Soil Will Save Us* ranges through several farmlands, from North Dakota to Zimbabwe. She deftly addresses this issue of quantifying how much carbon is actually sequestered.[18] As she notes, it's a tough undertaking: there's not enough research. "There certainly is a problem with ag departments and ag schools being heavily, heavily funded by businesses that have a stake in the status quo, have a stake in the kind of agriculture that uses a lot of chemicals, does a lot of tillage, and requires a lot of equipment and all of that," she tells me. The soil is a complex system, and it's hard to pull out one factor and change it, and then compare it to a control.

"The soil health practitioners see such dramatic changes on their own land because they're doing a lot of different things. They're doing cover crops, and they're doing compost, and they're doing no-till, and they're bringing in their animals to eat down the remaining vegetation. They're doing all these things that build up life in the soil and carbon in the soil, so I think it's natural that those people would feel very impatient with the slow and reductive pace of university science." As she says, the soils do become carbon rich. Ohlson points to the benefits to the whole system: reduction in runoff of fertilizer and other chemicals that pollute waterways; decreased air pollution from blowing dust; and increased soil permeability, meaning the system can resist droughts and floods. "There are so many benefits that come with this," she adds, "that the average person, even if they don't have a number to hang onto for carbon storage, for carbon sequestration … should still support this shift—which is a paradigm shift in agriculture, because it has so many benefits."

This may be a challenge for those of us fixated on empirical data or climate change narrowly defined, but it's a useful way of looking at reasons for pursuing soil carbon sequestration. Noah Deich, executive director of the nonprofit

Carbon180, also emphasizes the importance of moving in the right direction; the need right now is to begin the work, rather than get caught up in extra-precise quantification. "The question might be a question less of what is the ultimate scale potential, but what are the incentives? What are the policy designs? What are the corporate action campaigns? What are the consumer engagement campaigns that can reward producers for managing their land in a way that sequesters carbon on them? That's the first step … we need to just get started," he says.

Biochar

Over 2,000 years ago, in the Amazon, indigenous people were managing soils to be carbon rich. Deposits of these dark, fertile soils, called *terra preta*, can still be found today. *Terra preta* soils have inspired many advocates for biochar, which is essentially carbonized organic material that benefits soils by making them more fertile and helping them retain water. The basic idea is that biomass—crop residues, grass, other plants or trees—is combusted at low temperatures (300 to 600°C) without oxygen. This process (pyrolysis) results in charcoal, which is a form of organic carbon that can endure.

Permaculturist Albert Bates got turned on to biochar during his travels in the Amazon. Bates is an environmental rights lawyer, a cofounder of the Global Ecovillage Network, and a long-term resident at The Farm, an intentional community in Tennessee. He's been concerned about runaway climate change since the 1980s, and in 1989 he wrote his first book on the climate crisis. "I've been searching for solutions," he tells me over Skype from Mexico. "I was kind of despairing over everything, until I went to Brazil for a permaculture course … and got to travel into the Amazon and visit with some scientists there, and study the *terra preta* soils, and bring some back to Tennessee."

In their book, *Burn: Using Fire to Cool the Earth*, Bates and fellow biochar researcher Kathleen Draper describe various ways that biochar can be used to store carbon. They sketch out how we can go from wasting to banking carbon in virtuous cycles they call "carbon cascades." The authors travel through the world of biochar projects, from a village-scale biorefinery in China to an eco-lodge in the Dominican Republic. One option for carbon removal is what Bates and Draper describe as bioenergy with biochar capture and storage (or BEBCS, in contrast to BECCS). In our conversation, Bates explains to me that there's more that can be done with biochar besides enriching soils. Biochar can also go into road construction materials, and into aggregates used in cement and concrete. "Turns out that if you elevate the content in concrete with 8 percent to 12 percent biochar, it actually improves the quality of the concrete over what it had been with just sand," Bates tells me. It can also be used to improve permeability of surfaces, as has been experimented with in Stockholm. "We've got roads; we can look at the bitumen in asphalt. We can look at bridges, airports. We can start to think about composites other than steel, concrete and asphalt; we can think about plastics, and the monomers and polymers that go into the plastics. Many of those are enhanced, it turns out, by carbonates. So you can add biochar, pyrolized carbon, into composites, and now you get a stronger polymer."

Using biochar in the built environment would make it possible to employ biomass energy without being reliant on forestry or biomass energy crops, because it would be possible to use things that wouldn't normally go into agricultural soils. "When you start to talk about putting it in cement, putting it in highways, putting it in airports and roads and things like that, bitumen—now you can stand to add in plastics from municipal waste dumps and bio-solids from sewage treatment plants." Expanding the feedstock possibilities in this way would be a real breakthrough. "You don't divert from food or from biodiversity services of forests in order to feed your biomass energies," he tells me. "You can get your energy from pyrolysis from your sewage treatment plants, from your municipal landfills. All of those can go to make energy for you in vast quantities."

In *Burn*, Bates and Draper look at the potential of biochar when one includes sources like municipal waste, landfills, and so on. With biochar in agricultural soils, Bates comments that the drawdown potential would be one to four gigatons of carbon dioxide equivalent (or, similar to that of soil carbon), when emissions are around forty gigatons. "It isn't enough. We can talk about tree planting, we can talk about seaweed, we can talk about kelp farming … You sum them all together, and you're lucky if you get to seven or ten or even twelve gigatons of CO_2 per year removal." But if you look at biochars in these new sinks, "concrete airports and buildings, carbon fiber cars, polymers of various kinds, it works out to closer to fifty gigatons."

And it could scale very quickly, Bates argues: "Now we can be talking drawdowns … with ten gigatons a year coming out of the atmosphere, you can begin to calculate how many parts per million we can go down. From 410 down to 400 down to 390 down to 380, 370 and so forth. Well, yes and no. There's some problems with that approach to this. We've been adding carbon to the atmosphere for 100 or 200 years. We know that carbon added to the atmosphere makes it warm up; we know how the greenhouse effect works. We don't know how fast it responds when we start to withdraw carbon. We deprive the atmosphere of photosynthetic carbon: How fast does the temperature respond? How fast does the chemistry of the atmosphere and the oceans respond? We don't have any data set for the reverse of warming." So, Bates cautions, we don't actually have any proof of this. "That stands as a theory. That's waiting to be tested."

There isn't much peer-reviewed research on applications of biochar in the built environment, and virtually none of the scholarly meetings I attend on negative emissions science or governance discuss it. I ask Bates why it is that a writer and lawyer, a self-described hippie who lives in an intentional community and crowdfunds his work on Patreon, is the one who's looking into this. Bates, though, actually seems quite optimistic about the prospect that really good research universities and institutes will come in and up their game. Part of the promise of this idea, Bates points out, is that it flips the problem from just being about carbon to being about waste management. Another benefit is that it wouldn't require all the injection of carbon that CCS projects entail. "We don't need to gasify or liquefy carbon and pump it a mile under the earth or a mile down into the ocean, which would be a bad idea for a number of reasons," he explains. "Instead we can just solidify it into hard-scape and build our cities of the future, roadways and things of the future, that way." Rethinking our relationship with carbon and our view of waste is a beautiful vision. Their book is filled with frontline journalism documenting the creativity on the carbon frontier, where interesting ideas receive all too little attention from establishment science and policy, and hope blooms in unexpected places like sewage sludge or sidewalks.

Planting forests

Planting trees may be the most beloved option for dealing with climate change. There's a beautiful kindergarten simplicity to the image. Planting a tree is touted as something that every community can do, and communities benefit locally from the psychological and climate benefits of the green space. Reforestation on climate-significant scales, though, is a different beast.

One government that has been thinking about forest carbon sinks on a nation-state scale is Bhutan, the world’s first carbon-negative country. They manage this feat in part because of an abundance of hydropower, and because the country’s forests suck up more carbon than the nation produces. Bhutan’s constitution, enacted in 2008, mandates that a minimum of 60 percent of the country’s total land area must be forested at all times. It’s not just pure luck of geography, then, that keeps the country carbon negative; it’s also governance. What enables that kind of leadership?

The year the forest-protecting constitution was enacted was the same year that the new king, a twenty-eight-year-old reformer, was coronated. This was no ordinary coronation: the elder king had announced the transition of the monarchy into a democracy. People had come by truck, motorbike and yak from all regions of the country to see the former king place the Raven Crown on the head of his son. The ceremony was held on November 6, 2008, a date deemed auspicious by three enlightened astrologers. A Thursday: the eighth day of the ninth month of the earth male rat year.

I was visiting the country then, and sharing in the nation’s jubilant mood. The day before, Obama had claimed the US election. I was glued to the blurry BBC coverage, guiltily monopolizing the television of the Bhutanese family whose farmhouse I was staying in. Occasionally, an eighteen-year-old boy named Singye would join me in watching the coverage. We sat upon carpets in the bare room and drank tea while I tried to explain what was going on with all the revelers in the streets of Chicago: a quarter of a million Americans, or more than a third of Bhutan’s population, turned out to celebrate.

“We have a new leader right now, too.”

“What’s his name?”

“Barack Obama.”

“Is he married?”

“Yes, with two children.” Singye nodded.

In Bhutan’s capital, Thimphu, they celebrated their new leader for three days: solemn ceremonies, concerts with traditional dance, archery. In honor of the coronation, all mobile phone communications were shut down during the day. The streets were lined with Buddhist flags: bright red, yellow, blue, green, white. At night, the trees and buildings were festooned with strings of rainbow light.

In my conversations, I had been surprised to learn that people were excited about the transition to the young Dragon King, but often less enthused about the transition to democracy. People adored the monarchy. They'd seen conflict and corruption while watching elections in neighboring India, and they weren't sure if they wanted their country to go that route. I observed the festivities from a hill, across the river from the seventeenth-century fortress in Thimphu where the coronation ceremony was taking place. While watching the crowds gather, I ran into another foreigner—a development professional. I told him what I'd been hearing about this governmental transition, about the wariness toward democracy. He responded with an anecdote about working in Vietnam, a one-party state that could implement policy shifts quickly. One day, the government had decided that everyone needed helmets for motorcycles, and the next day, everyone had them. "Like that," he said, snapping his fingers.

Bhutan is a standout example of how even in a democracy, a carbon-negative target can be achieved. It doesn't necessarily require autocratic fiat or loving decree to make these land-use decisions. Of course, the practicalities of scaling up forest management and carbon-negative land use beyond a small, mountainous, sparsely developed country prompt the question: What kind of government could achieve this goal? To sequester one gigaton of carbon dioxide, one would have to afforest 70 to 90 million hectares, or a land area about twice the size of California.[19] Now, again, current emissions are forty gigatons of carbon dioxide. So that's a tremendous effort just to put away one gigaton. A few gigatons are certainly doable, since there's a lot of farmland that's been abandoned because of low productivity; one conservative estimate put the acreage at around the size of India.[20] Scientists calculate that there are large areas of land available for reforestation—from 500 million hectares in bottom-up estimates, to between 1 and 3 billion hectares in modeled estimates of nonagricultural land broadly.[21]

But how can the transition be orchestrated, and how many times can that feat be repeated? A finite number of times. Consider figures like those outlined in "Alternative Pathways to the 1.5°C Target Reduce the Need for Negative Emission Technologies," a helpful analysis by a European group of modelers (reported eagerly in the environmental press as "World Can Limit Warming to 1.5°C 'without BECCS.'")[22] How did the modelers do it? For starters, they assumed capture of 400 gigatons by reforestation. But here's the assumption you have to dig out of the details: in their scenario, agricultural efficiency increases, and massive areas of cropland and grazing land are converted to forests. Next, this storyline “assumes a technological breakthrough and mainstream acceptance of cultured meat, starting in 2035 … We assume that by 2050, 80 percent of meat and eggs (but not fish and seafood) are replaced by cultivated meat, which is grown directly from corn and small amounts of soy.”[23]

Indeed, if we switch to “cultivated meat,” grown from cells in vats, or just to plant-based meat, then we can plant trees on the vast swaths of land that are currently being grazed for meat production. But at this point, we’re not just talking about an afforestation project. We’re talking about cultural and behavioral change in countries who value meat, including getting them to accept something as new and potentially weird as lab-grown meat; about telling people who just gained the economic capacity to *have* meat that they should switch to something else; about defanging a powerful industry lobby; about telling scores of pastoralists that they need to adopt different livelihoods. This is more than “afforestation” in a simple sense. It’s a social project, enrolling education, public health, and more. Afforestation on this scale is basically geoengineering. Whether that dramatic transformation is easier, better, or more desirable than all the other approaches to removing carbon should be a vibrant matter of debate. But it’s not as simple as planting a seed in the earth.

Talk of forest creation begs the question: What exactly is a “forest”? There are things that look like forests, but they may not be carbon rich. A recent study in *Science* showed that Europe has been considerably afforested since 1750—with an increase of 10 percent over this period (most of it from 1850 to present). During this transition, 85 percent of the forests were put into management. Yet two and a half centuries of managing these forests has not contributed to cooling. Instead, converting deciduous forests into coniferous forests changed the albedo (the proportion of the light reflected by the earth’s surface), canopy roughness, and evapotranspiration from the land, which warmed things up. Europe’s forests accumulated a carbon debt of 3.1 gigatons over this time, as the extraction of wood released carbon that was stored in biomass, litter, deadwood, and soil carbon.[24] Most biomass carbon is in the woody stems and roots of old trees, and primary forests store 30 to 70 percent more carbon than commercially logged or plantation forests. It takes hundreds of years to grow these carbon stocks to their natural capacity.[25] There’s also a big difference between tropical and boreal forests, and the net climate effect of increasing boreal forest is unclear.[26]

Moreover, scientists have been sobered to find that trees can emit methane and volatile organic compounds, which could offset their cooling effects.[27] Complicating it further, afforestation schemes need to be "climate smart" by accounting for projected climate impacts, including extreme storm events or outbreaks of forest diseases and pests. Forests may be a risky place to bet on for carbon storage, because in the event of wildfires or die-offs, the carbon could be lost.

Yet from Bhutan to the Sahel's so-called "Great Green Wall" to China's national reforestation project, aspirations for afforestation and reforestation are vast. Emerging technologies, like aerial planting of seedlings via drones, may aid states and organizations in their efforts. Theoretically, governments can play a large role in this. Much forestland is within the purview of governments: one-third of Latin American forests, about two-thirds in Asia, and virtually the entire area of forests in Africa.[28] However, one problem with making calculations around the ability of countries to command afforestation or reforestation is the assumption that developing countries have full control over the lands and actors within their borders, notes geographer Jon Unruh. He points to the problems of enforcement, deep and long-lasting resistance to and suspicion of land-related policies, corruption, and discrimination.[29] Existing forest carbon schemes such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation, the program under the UN Framework Convention on Climate Change) have run into a host of documented problems: the inadequacy of certification schemes to protect livelihoods and biodiversity when pursuing climate goals,[30] the ways in which "carbon colonialism" via plantation forestry amounts to neoliberal land grabs,[31] and many others. On the other hand, research has also shown how agricultural intensification, land use zoning, forest protection, increased reliance on imported food and wood products, and foreign capital investments can all work together in managing land use transitions.[32] What's clear is that it's not useful to treat afforestation as something that happens "over there," in the forest. Rather, it's a complex social project that touches all of us—at the very least, through what we choose to eat every day. That juicy hamburger could instead be a tree storing carbon: modeled pathways for keeping warming to 1.5°C assume that it will become one.

Blue Carbon

Carbon stored in peatlands, mangroves, tidal marshes, and seagrasses is collectively known as “blue carbon.” These areas are thought to be hot spots for storing carbon, and so one of the best things for the climate would be to stop destroying wetlands. One-third of the world’s mangrove, seagrass, and salt marsh areas have been decimated over the past several decades.[33] They are being degraded at devastating rates—in some instances, up to four times that of rainforests.[34] Between 2 and 7 percent of blue carbon sinks are being lost annually, which is a crazy rate of decline. Protecting these ecosystems could contribute powerfully to mitigation. One UN report estimated that doing so could amount to 10 percent of the reductions needed to keep CO_2 concentrations below 450 parts per million.[35] Seagrass meadows are particularly impressive: they can sequester carbon for millennia. Sediments in healthy coastal ecosystems can continue to accrete carbon vertically as sea levels rise. This means they can keep building up carbon, unlike the terrestrial carbon sinks, which become saturated in a few decades.

Enhancement of blue carbon via wetland restoration and protection seems like one of the carbon removal approaches with the fewest drawbacks. It’s something that can go alongside existing restoration and coastal adaptation / shoreline protection projects. For example, biochar and other carbon-rich materials could be used in these projects to sequester even more carbon. Despite its potential importance, blue carbon has scarcely been addressed in the literature on “climate engineering,” at least up until the 2018 National Academies report put it on the research agenda for “negative emissions.” I asked marine geochemist Sophia Johannessen about this apparent omission. She explained that it’s a new field: “These papers started to appear in about 2001, and the field has expanded rapidly since them.” Johannessen is actually at the center of a lively scientific debate on this topic, in the wake of a 2016 paper she published with fellow Fisheries and Oceans Canada colleague Robie Macdonald: “Geoengineering with Seagrasses: Is Credit Due where Credit Is Given?”[36] In it, they argue that while seagrasses are reported to account for up to 18 percent of the carbon burial in the world’s oceans, the accounting is wrong because it doesn’t address how carbon is deposited in marine sediment. In fact, estimates may be off by 11- to 3,000-fold. I asked her what accounts for the incredible variance in assessments, and she speculated that it might be disciplinary boundaries between two communities of research. “The people who are publishing these papers, saying that there’s a huge sequestration potential in seagrasses, haven’t been working in marine sediment geochemistry,” she replied. “They know about the biology of seagrasses, but they don’t really understand how sediments process and sequester carbon.”

Biologists are naturally intrigued by sequestration in seagrass meadows because seagrasses are crucial habitat for juvenile fish. But these ecosystems, being right at the coastlines, are under threat from urban development. Carbon sequestration would add a compelling reason to protect seagrasses. Yet to a marine geochemist, carbon sequestration in seagrass seems elusive. First of all, most of the carbon that’s sequestered in coastal sediments isn’t sequestered where seagrass grows. Organic carbon sticks best to very fine particles. But seagrasses generally grow in coarser sediment, like sand—so the places where the seagrass is growing aren’t really the places where carbon tends to build up. Another issue is that a lot of global estimates of carbon sequestration in seagrass meadows are based on measurements of one specific type of seagrass that grows in beds in the Mediterranean and Southern Australia, *Posidonia*. It has extremely long root mattes that extend for meters into the ocean floor. These root mattes are not the norm for seagrasses generally, yet measurements from *Posidonia* haven been extrapolated throughout the world.

Coastal sediments, root mattes: this all sounds pretty obscure. But the stakes for getting it right are high, because the first international protocols are now emerging around the voluntary market for carbon burial via seagrass. Sequestration in seagrass meadows could therefore be used to offset emissions elsewhere. “But if the seagrasses really aren’t actually storing as much as people think, and credits for planting seagrasses are used to offset emissions elsewhere, then the net effect could be an increase of carbon emissions into the atmosphere —just the opposite of what carbon credits are supposed to achieve. So it’s a really important topic, even though it sounds boringly technical.” Johannessen explains, summarizing the short story: Seagrasses are important for habitat and protecting coastlines. “Some people have said that seagrasses also bury a lot of organic carbon, and that we should be able to claim carbon credits for protecting or restoring them. Marine geochemists reply that the current accounting methods are wrong, and the estimates are far too high. But there is methodology that can be used so that people actually could assess carbon storage in seagrass meadows properly, and there is a potential for it to be used for claiming carbon credits in the future.”

On one hand, it's disheartening to see how information about carbon removal can fall into this void between disciplines and lead to these technical mistakes in calculating global potential—we could probably find similar illustrative examples for every other carbon removal technique, too. On the other hand, it's promising to see the scientific process engaged and self-correcting, lending hope to the idea that maybe we will have better estimates to guide us in the future. Yet even if we did have perfect knowledge about how much carbon all these practices could sequester, would people act on it?

Will natural carbon removal fulfill our hopes?

These regenerative, land-based approaches to carbon sequestration are exciting in part because people bring such love, care, and devotion to them. Through these conversations about regeneration and natural climate solutions, people are developing a broader vision for how to live with the earth in the future.

This capacity to envision alternate futures is precisely what is needed. It is invigorating a stale climate politics with grassroots energy. And yet, in terms of the capacity of natural climate solutions to not only mitigate but *reverse* climate change, there are three sobering realities that must be kept in mind.

The first is the difference between one-off removal and continual removal. Both large-scale afforestation and soil carbon sequestration face this issue of being techniques whose storage capacity levels off over time. Second, many natural climate solutions aren't permanent—they require maintenance and could be reversed by future decisions, as well as by climate change itself. For example, some research on conservation tillage shows that it may only increase soil carbon to a depth of ten centimeters. Because this thin layer is very vulnerable to changes in management, agricultural practices may not sustain surface soil carbon over the centuries or millennia for which climate policies must be designed.[37] However, this maintenance requirement should not be thought of simply as a burden or liability. "Though premised on a logic of escape and exit, the marking of buried materials is also tied to the marking of sites of ongoing obligation," write Kearnes and Rickards.[38] These types of obligation and care are of a very different logic than our society has been running on. But care and the intention to maintain carbon can only go so far: if left unchecked, climate change could reverse terrestrial carbon sinks by mid century.[39] Wind and rain will erode soil into the ocean; fires will burn down forests. In this sense, the efficacy of the solutions is vulnerable to the problem itself.

A third reality concerns the scale of these measures' results compared with the scale of emissions. Remember, current emissions are on the order of forty gigatons of CO_2 per year, or fifty gigatons of CO_2 equivalent when you count other greenhouse gases. Afforestation, soil carbon, and biochar, at the *extremes* of their socio-technical potential, could remove perhaps ten to twenty gigatons of CO_2 equivalent per year of that (as per the 2017 UN Environment Programme's *Emissions Gap Report*). But this would be a tremendous work of social and industrial transformation. This highlights, first, the need to stop emitting. It's impossible for these techniques to make up for our current levels of carbon emissions. And this peak in emissions needs to happen right away. For even if you view the problem on a longer time frame, say 200 or 300 years, those natural sinks will be sequestering their ten gigatons CO_2 equivalent per year for, say, 50 years—then they will be full.

Try this thought experiment. Imagine that emissions flatline in 2020; the world puts in a strong effort to hold them steady, but it doesn't manage to start decreasing them until 2030. It's plausible that it would take ten years to start a worldwide decrease, right? But ten years steady at 50 Gt CO_2eq—and there goes another 500 GtCO_2eq into the atmosphere. That one decade would cancel out the 500 GtCO_2eq the soils and forests could sequester over the next fifty years (sequestered at an *extreme* amount of effort and coordination among people around the whole world). Plateauing emissions for a decade before starting to bring them down might not sound that bad—the world would probably celebrate that triumph—but it would take fifty years of Herculean effort in enhancing these natural sinks *just to make up for that decade alone* of flat emissions. Then, the sinks would be maxed out in terms of additional removals. But we'd still have to maintain the storage, or we'd risk releasing the carbon again. Moreover, there wouldn't be enough sink capacity later on in the century to make up for small amounts of continued emissions from some hard-to-mitigate sectors, like shipping, aviation, steel, or rice production.

The above calculations, rough as they are, lead me to conclude that it's very risky to rely on natural climate solutions alone. I'm concerned we could risk placing all of our regeneratively grown eggs into one lovely, but small, regeneratively grown basket. If you're absolutely sure not only that emissions will decline very sharply over the next ten years, but that natural climate solutions will be as effective as we hope, and also that global demand for meat will stop rising and decrease dramatically—if you would bet it all on everything going just right—then okay, perhaps natural carbon removal is all we need. I don't know anyone that would place that bet, however. Moreover, I'm worried about what happens when books are published, countless YouTube videos are recorded, and conference halls are packed with people, all propagating the notion that soil can magically suck up all the carbon that's been burned. It's so intuitive that we should be able to save the planet through care: regenerative agriculture seems like it *should* be the right answer. It feels right and good to source hope there. Nevertheless, I'm concerned that this determined post-truth faith in soils could contribute to a failure to invest in other technologies that are also needed for this gargantuan carbon removal challenge.

When it comes to afforestation, regenerative agriculture, biochar, and blue carbon, climate change may actually be the least compelling reason to take many of these actions. We should regrow complex forests for their biodiversity benefits, establish agroforestry because it increases farmer resilience, recycle crop residues in order to create a circular economy, improve farm information systems to help farmers, and take care of the soil so as to avoid dead zones in the oceans—and much, much, more. Climate benefits are a fantastic bonus to these efforts, but the current magnitude of emissions overwhelms what these sinks can address during this century. We are deluding ourselves if we think this can be the *only* response to the disaster faced by people and species around the world. Natural climate solutions should be pursued with all the energy we can muster, and they really *can* make a contribution. But if we genuinely care about lessening climate impacts, curbing sea level rise, or saving species, other measures will also be needed.

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