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Carbon Removal to the Rescue?

SIMON NICHOLSON

Every year, the global atmospheric concentration of greenhouse gases is rising. Human activities annually expel a combined 40 billion metric tonnes (40 gigatonnes) of carbon dioxide. The figure grows to around 50 gigatonnes of carbon dioxide equivalent when other greenhouse gases like methane and nitrous oxides are taken into account. This emitting of greenhouse gases is one component of the inexorable math of climate change: we humans, collectively, have been building up year after year the stock of greenhouse gases blanketing the planet, and as that stock grows, global warming and associated climate-related risks intensify.

Temperatures will continue to creep upward until, a few scientific provisos aside, the annual human contribution to the atmospheric load of greenhouse gases is reduced to zero. This insight runs up against a second component of climate change math: there is a slim and narrowing window to slash the overall net flow of greenhouse gases in order to keep average atmospheric temperatures from rising above critical thresholds.

The international negotiations that led to the Paris Agreement in 2015 have set the upper acceptable warming threshold at 2 degrees Celsius above pre-industrial averages, with the countries of the world further agreeing to do everything possible to limit warming to no more than 1.5°C. Already, the world has warmed by around 1°C. The first portion of the most recent report from the Intergovernmental Panel on Climate Change (IPCC), released in August 2021, suggests that the Earth is on track, across a range of near-future

scenarios, to cross the 1.5°C mark sometime between 2030 and 2035.

Every year, then, in which human-caused greenhouse gas emissions are more than zero, the remaining “carbon budgets” associated with 1.5 or 2 degrees of warming shrink and the negative impacts associated with global heating grow. What does reaching zero emissions entail? The first order of business has to be what some call deep decarbonization. This is the work of transforming the built environment and energy, transportation, and agricultural systems in order to halt, as much as possible, the use of fossil fuels, and curtail land use practices and changes that contribute to emissions of greenhouse gases.

Now, though, as carbon budgets tighten and climate impacts worsen, the mitigation component of climate action must mean more than limiting the outpouring of greenhouse gases. In recent years, a slew of scientific assessments has made it clear that slashing emissions will need to be supplemented with other actions. Even as work is undertaken to halt flows into the atmosphere of human-caused greenhouse gases, excess carbon dioxide must also be *removed* from the atmosphere.

This is the starting point for any conversation about carbon removal. Sometimes also called carbon dioxide removal, greenhouse gas removal, or negative emissions technology, this process involves pulling carbon dioxide out of the atmosphere and directing it to long-term storage or to beneficial use. There is a wide variety of currently available or imagined land and ocean management practices and technologies that could support this carbon removal function.

Such practices and technologies, described in more detail below, could play at least three roles in climate policy. First, carbon removal could act to essentially expand the existing carbon budget, by removing carbon dioxide at the same time as

SIMON NICHOLSON is an associate professor of international relations at American University, where he is also a co-founder of the Forum for Climate Engineering Assessment and the Institute for Carbon Removal Law and Policy.

deep decarbonization actions are being implemented and scaled up. Expanding the carbon budget creates more time for other climate change response options to take hold and more breathing room before critical temperature thresholds are crossed, with less likelihood of drastic ecological or societal disruptions or of a need for draconian reactions.

Second, carbon removal could play a kind of clean-up role, offsetting continued emissions that will be hard to abate in some sectors of the global economy. Think, for instance, of the potential deployment of carbon removal options to account for the possibility that certain kinds of heavy industry or transportation might continue to rely on fossil fuel use for the foreseeable future.

Third, carbon removal could play a restorative role, turning back the dial on decades and centuries of atmospheric concentrations of carbon dioxide. Ultimately, carbon removal could take the planet back closer to the climatic conditions that facilitated the rise of human civilization, or reverse an “overshoot” in which climate change responses are not sweeping or rapid enough to avoid the crossing of temperature thresholds.

The possibility of such roles for carbon removal approaches is signaled by the Paris Agreement. The Agreement calls, in Article 4, for balancing greenhouse gas emissions and removals by mid-century. This language has given rise to a spate of “net zero” pledges from many countries and companies, charting a pathway to reaching zero emissions not only by reducing greenhouse gas outflows but also by depending to some extent on carbon removal options. It has also led to rising levels of public and private spending on carbon removal research and purchases of carbon removal services.

Recent IPCC reports further suggest that over the latter half of the century, there will likely be a need to go beyond net zero to “net negative”—a scenario in which more carbon dioxide is being pulled each year from the atmosphere than is being emitted from human sources. Many of the scenarios examined in IPCC reports that would keep warming beneath 1.5 or 2°C posit carbon removal of 10 gigatonnes or more per year by the time the 2050s roll around. For a sense of scale, remember that annual human emissions today equal around 50 gigatonnes of carbon dioxide equivalent.

Still, even as the need for some role for carbon removal in climate action has come more clearly into focus, and as carbon removal options are moving from chalkboards to the real world, such schemes are subject to a range of persistent questions and challenges. In some civil society and academic circles, in particular, carbon removal remains a controversial notion. The possibility that it might grow to play a larger role in humanity’s response to climate change is derided by some as a “false solution,” a distraction from the real work that needs to be done on deep decarbonization and the building of more equitable societies, or a potential boon for fossil fuel interests intent on keeping their core business models intact. Carbon removal options also raise a host of technical, political, and justice-related issues that may limit the scale at which any or all of these approaches can ever be utilized.

Here’s the bottom line: carbon removal must now be considered an essential component of climate action, but not all forms of carbon removal are created equal. Carbon removal done well—

meaning options developed and deployed at appropriate scales, with strong environmental and social protections, and linked to actions aimed at keeping deep decarbonization as the overriding

priority for climate action—could be an important component of the transition to a climate-safe world. Carbon removal done poorly, however, could lead to a lock-in of the very social, political, and economic processes that have given rise to the climate crisis.

There is a pressing need to research the technical and engineering aspects of carbon removal in order to better understand what might be possible, and at the same time to work to set in place the rules of the road that can guide carbon removal in the best possible directions. This is the work needed to ensure that carbon removal programs are effective as well as attentive to both environmental sustainability and social justice.

WHAT IS CARBON REMOVAL?

There are many different potential approaches to carbon removal. In developing a taxonomy, it helps to think about carbon removal as a two-step process. Step one has to do with drawing down carbon dioxide from the atmosphere. Step two involves doing something with that captured carbon.

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The potential pathways involved in the capturing step can be placed, broadly speaking, into two buckets. In one of the capture buckets are biological options, like planting trees and managing soils. In the other bucket is a set of mechanical or engineered options for carbon dioxide drawdown, including direct air capture and what is known as enhanced mineralization or enhanced weathering.

When it comes to step two—doing something with the carbon—most biological drawdown options operate to hold captured carbon dioxide in biological systems. (There are a couple of major exceptions to this, outlined below.) Engineered and mechanical drawdown, by contrast, may direct the captured carbon dioxide into long-lived products or into long-term sequestration, either deep underground or in rock formations.

Before proceeding, there is one important aside to make. The carbon removal options discussed here are not to be confused with the carbon capture and storage (CCS) systems used at fossil-fueled power plants or industrial facilities. This kind of traditional CCS technology can help, when it works, to *reduce the flow of carbon dioxide* into the atmosphere. Traditional CCS acts, in other words, as a way to slow down the rate at which greenhouse gas concentrations are rising.

Carbon removal is different. When it works, carbon removal actually *reduces atmospheric concentrations of carbon dioxide*. The goal is to pull carbon dioxide directly from the open air, where it contributes to climate change, and render it benign in climate terms.

This is why I just referred to long-lived products and long-term biological or underground storage, or holding carbon dioxide in rock formations. By contrast, if captured carbon dioxide is directed into a short-lived product like a fuel, it will quickly find its way back into the atmosphere, resulting in a kind of carbon recycling but not true carbon removal. These distinctions may seem a little arcane, but they matter for the crafting of policy and for nuanced consideration of different climate response options and their social consequences.

BIOLOGICAL POSSIBILITIES

So what are some of the major carbon removal options that are either in development or in discussion? The terrestrial (that is, land-based) biological options are most familiar. Planting trees and working to protect and expand existing forests

are tried and true means of pulling carbon dioxide from the atmosphere and storing it. Likewise, restorative farming practices can operate to drive carbon dioxide into storage in soils. A related approach involves the introduction into soils of biochar, a substance created by heating organic matter in the absence of oxygen. The biochar can act as a production-boosting soil augmentation, while adding to the stock of carbon dioxide that soils hold in storage (unlike traditional nitrate fertilizers, which are a contributor to climate change).

The oceans also offer opportunities for drawing down and storing carbon dioxide via biological pathways. So-called blue carbon options include the restoration and maintenance of coastal wetlands and seagrass beds. A more exotic option is known as ocean iron fertilization, which involves depositing iron filings into relatively iron-scarce regions of the open ocean. There, the iron can act as a kind of fertilizer, causing blooms of microscopic phytoplankton that absorb atmospheric carbon dioxide as they grow. The phytoplankton potentially can hold some of that carbon in storage as they die and sink to the ocean floor.

The open ocean is of interest to carbon removal startup companies like Running Tide, which is investigating the potential for capturing carbon dioxide by growing kelp tethered to buoys out at sea, with the aim of then sinking the kelp for the purpose of carbon dioxide storage in the deep ocean. (Such commercial undertakings may ultimately be money-making enterprises should a price ever be put on carbon dioxide pollution by governments. At the moment, though, carbon removal companies either are relying on funding from venture capitalists or the relatively small group of companies and other entities willing to pay voluntarily for carbon removal services, or are exploring carbon removal in an effort simply to do something good for the environment.)

A further ocean-based biological approach is offered by artificial upwelling and downwelling, which involve pulling up nutrients from lower ocean boundaries to make them available to life toward the ocean surface. The sinking of some of the resulting increase in biological matter could, as with ocean iron fertilization and kelp farming, help store carbon dioxide away from the atmosphere.

Some call these kinds of biological pathways to carbon dioxide removal and sequestration “nature-based solutions,” though options like

ocean iron fertilization and artificial upwelling stretch such categories due to their engineered character. Exactly what does and does not count as “nature-based” matters for the ways in which nongovernmental organizations, policymakers, and society at large understand carbon removal options. Those options that appear (or can be made to appear) “natural” tend to be easier for the civil society actors and the broader public to support.

Biological approaches to carbon dioxide drawdown and storage offer great potential to contribute to an effective climate change response. One challenge, though, is keeping carbon dioxide in storage in biological systems once the gas has been captured. Soils can be plowed, restored coastal ecosystems disturbed, forests burned or cut down. This means that biological carbon sequestration must be coupled with careful, robust, long-term management in order to have positive climatic effects.

The world’s forests, for instance, currently operate each year as a vast and expanding carbon dioxide sink. Recent analysis from Global Forest Watch indicates that forests sequestered twice as much carbon as they emitted between 2001 and 2020, for a net absorption of around 7.6 gigatonnes of drawdown and storage per year. But many of the forest ecosystems are under severe threat from cutting, forest fires, and the introduction of pests by humans. The latter two issues are made worse by climate change.

Biological approaches, like engineered alternatives, pose social and political challenges. These have to do, for instance, with whether and how carbon removal options can be managed for social as well as environmental benefit, whether carbon removal efforts might divert resources and attention away from other efforts to tackle climate change, and how to manage other related social and environmental risks.

Two additional carbon storage options for plant matter grown on land are worthy of attention. The first is what has become known as “mass timber construction.” This involves using specialized wood products, which have sequestered carbon dioxide from the atmosphere, in construction—including for high-rise buildings. The materials lock the carbon dioxide away for the life of the structure. This approach is gaining ground particularly in Scandinavia.

A second storage option is known as bioenergy with carbon capture and storage (BECCS). This process, in small-scale testing in a few places, involves growing some kind of biomass—say, an oil plant like palm oil or a starch-filled plant like corn—that pulls down carbon dioxide from the atmosphere as it grows. The plant matter can then be burned directly for energy or turned into a liquid fuel, with the carbon dioxide emitted during combustion captured for underground storage. The stream of carbon dioxide produced during the operation of a BECCS facility could also conceivably be directed toward the manufacturing of certain products. If utilized in a long-lived product like cement, this could make for long-term carbon removal, locking carbon dioxide away for decades or centuries.

ENGINEERED OPTIONS

This extraction of carbon dioxide that can be directed to long-term storage or to some kind of industrial use is something that BECCS has in common with one of the engineered carbon drawdown options, direct air capture (DAC). A handful of DAC facilities are operating worldwide at pilot scale. One of these, the Orca plant run by Climeworks in Iceland, is now up and running as a commercial carbon removal enterprise, with the potential to move 4,000 tonnes of carbon dioxide into long-term storage each year. Although that would be an impressive feat, 4,000 tonnes is nowhere near the scale in gigatonnes that would make a difference in climate terms, so even this commercial endeavor can best be viewed as a test or proof of concept.

DAC facilities operate by varied means, but all of them involve directing streams of open air over a chemical membrane or electrode. Chemical reactions then separate the carbon dioxide from the other gases in the stream, and further reactions or manipulations can transform the gas into a form suitable for storage or use.

There is growing corporate and governmental interest in DAC. The US government, for instance, in one version of infrastructure legislation under negotiation in the House and Senate has proposed to devote \$3.5 billion to the establishment of what are being described as four DAC “hubs.”

Another potential engineered approach to carbon removal is “enhanced weathering” or

The oceans also offer opportunities for drawing down and storing carbon dioxide.

“enhanced mineralization.” This process would artificially speed up Earth’s carbon cycle, accelerating by many times the rate at which carbon dioxide in the atmosphere makes its way into rock formations. The most straightforward form of enhanced weathering involves the mining, grinding, and dispersal of reactive rocks such as olivine or basalt. Grinding the rocks increases the surface area available to the open atmosphere, speeding naturally occurring chemical reactions.

A start-up company called Future Forest is conducting a field test in Scotland, spreading finely ground basalt on a forest floor. The aim is not only to sequester carbon dioxide directly through the basalt’s reactions with the atmosphere, but also to encourage greater tree and plant growth. Another company, Project Vesta, is investigating the potential of spreading olivine on beaches. The idea is that wave action could further grind the rock, encouraging speedier drawdown of carbon dioxide.

DAC and enhanced weathering both offer the benefit that the carbon dioxide captured using those methods could conceivably be put into safe storage for long time periods. DAC is currently expensive, though, and enhanced weathering is relatively untested, raising questions about the extent to which these options can be scaled up.

Ultimately, what’s clear is that we have a wide and growing array of potential options that could facilitate the large-scale removal and storage of carbon dioxide. Some of the “nature-based” options are quite well understood in their technical facets and have broad support, but may be able to hold only limited quantities of carbon dioxide in storage over climate-relevant timelines, meaning decades or centuries. Some of the more speculative options, like DAC and enhanced weathering, offer vast potential but come with a set of environmental risks and technical and cost hurdles that may ultimately limit the scales at which they can be utilized.

What all of the carbon removal options currently being discussed have in common is the fact that they would require a great deal of time in operation to bring down atmospheric levels of carbon dioxide to such an extent that climate benefits could accrue. This observation has at least two implications. First, if carbon removal is to play any kind of role later this century in helping to address climate change, large-scale investigation into the various options must begin now. Second, no single

carbon removal option can be considered all alone as a way to tackle climate change. Instead, a whole portfolio of carbon removal options will likely be needed at various scales in various places, and carbon removal itself must be viewed as an addition to—not a replacement for—efforts to reduce greenhouse gas emissions.

SOCIAL CONCERNS

These different possible approaches to carbon removal offer real potential as one component of a multipronged response to climate change, even if there are many technical hurdles that would need to be surmounted for carbon removal to operate at climate-relevant scales. In addition, there are some thorny political and social challenges associated collectively with all carbon removal options, as well as specific challenges attached to individual approaches.

At the level of collective challenges, first and foremost is the concern expressed by some academics and civil society actors that carbon removal options represent a “false solution.” Some attach that label just to engineered approaches like DAC, enhanced weathering, and ocean iron fertilization, expressing a sense that the technologies and interventions represented by such approaches are part and parcel of the hubristic orientation toward nature that has given rise to climate change.

Others are skeptical even of nature-based solutions, citing the ways in which the planting of trees and the like have been used by some corporations as carbon offsets (involving the purchase of, say, the carbon removal services provided by a portion of a growing forest, to “offset” the emissions that a company itself is producing). These critics say such practices relieve businesses of pressure to pursue the transformational deep decarbonization actions that are necessary, instead allowing them to claim absolution through hard-to-verify third-party actions.

The false solution idea has also cropped up in debates over environmental justice. A report released in May 2021 by the Biden administration’s new White House Environmental Justice Advisory Council made the claim that DAC cannot be developed in ways that benefit communities and, for that reason, deemed it a form of climate response that is incompatible with environmental justice principles. Yet others have argued that, based on climate math and scientific assessments, DAC must at least be investigated—and that there

are many pathways to community engagement with, and benefit from, such projects.

Sorting through the thicket of environmental justice claims, particularly about engineered carbon removal but also regarding nature-based responses, is vitally important. Incorporating thorough consideration of these concerns into decision-making can help ensure the best possible outcomes for those with the most to lose, both from carbon removal done poorly and from worsening climate change impacts.

Critics have also pointed out that it is not clear how receptive people might be to the land use changes that, say, massive BECCS operations would entail, or the pipelines needed to move captured carbon dioxide to storage locations that would accompany development of DAC facilities, or the potential negative implications for human and environmental health entailed by grinding up and spreading minerals for enhanced weathering. Each carbon removal option needs to be looked at not just in terms of its technical potential to help draw carbon dioxide out of the atmosphere, but also in terms of social and environmental co-benefits and risks. This suggests a need for both disaggregation of carbon removal options into particular projects and granular assessment of those projects.

To take one example, an activity like tree planting sounds positive on its face. But there is a whole host of questions that need to be asked about any given tree planting project. The answers will determine the degree to which the project is beneficial in technical, environmental, and social terms. What mix of tree species is being planted, in what geography, over what area of land? To what extent are local people and livelihoods being taken into account in planning and implementation processes? To whom are the benefits associated with the project flowing, and how are potential risks and costs being apportioned? What about the environmental co-benefits and downside risks? And so on.

It is one thing for scientific assessments based on computer modeling to call for massive amounts of carbon removal. It is another thing entirely for particular projects to be developed in particular places, with all of the many forms of social

engagement that such enterprises entail. What we learn from a look at these political and social challenges is that projects like tree planting and management or the building of DAC facilities are far more than just technical or technological undertakings. They are also social projects, in at least a few senses.

First, any technical enterprise requires mustering and directing social resources like money, labor, and support. Second, there will be ongoing contestation over carbon removal options from the very largest scale (Is carbon removal needed? Is it desirable?) to the smallest (Why is that DAC plant being built in my neighborhood?). Third, there are very different ways to take the idea of something like enhanced weathering or soil augmentation with biochar into the real world, with differing levels of attention to broader social and environmental needs and conditions, producing different sets of winners and losers.

Climate models tend to suggest that there is still some time left for bringing large-scale carbon removal online. The currently accepted wisdom is that carbon removal will have to be scaled up over the second half of this century. But there is more urgency associated with the investigation of the emerging technologies, to see whether any of the contemplated options can pan out and to make sure that plans for implementation proceed along socially and environmentally desirable paths. Most of the analyses of carbon removal options to date have focused on absolute or relative cost and technical potential, paying too little attention to the social dimensions.

As interest in carbon removal grows, so, too, does the need to create the rules of the road that will help guide the process. Already, even before we know the extent to which various options may prove viable, the dual facts of the need for and promise of carbon removal are shaping flows of money and policymaking. Carbon removal that is done well promises to be an important and useful part of humanity's climate change response. Carbon removal done poorly, however, could simply entrench the same social dynamics and power structures that got the world into the climate change mess in the first place. ■

Carbon removal raises a host of technical, political, and justice-related issues.
