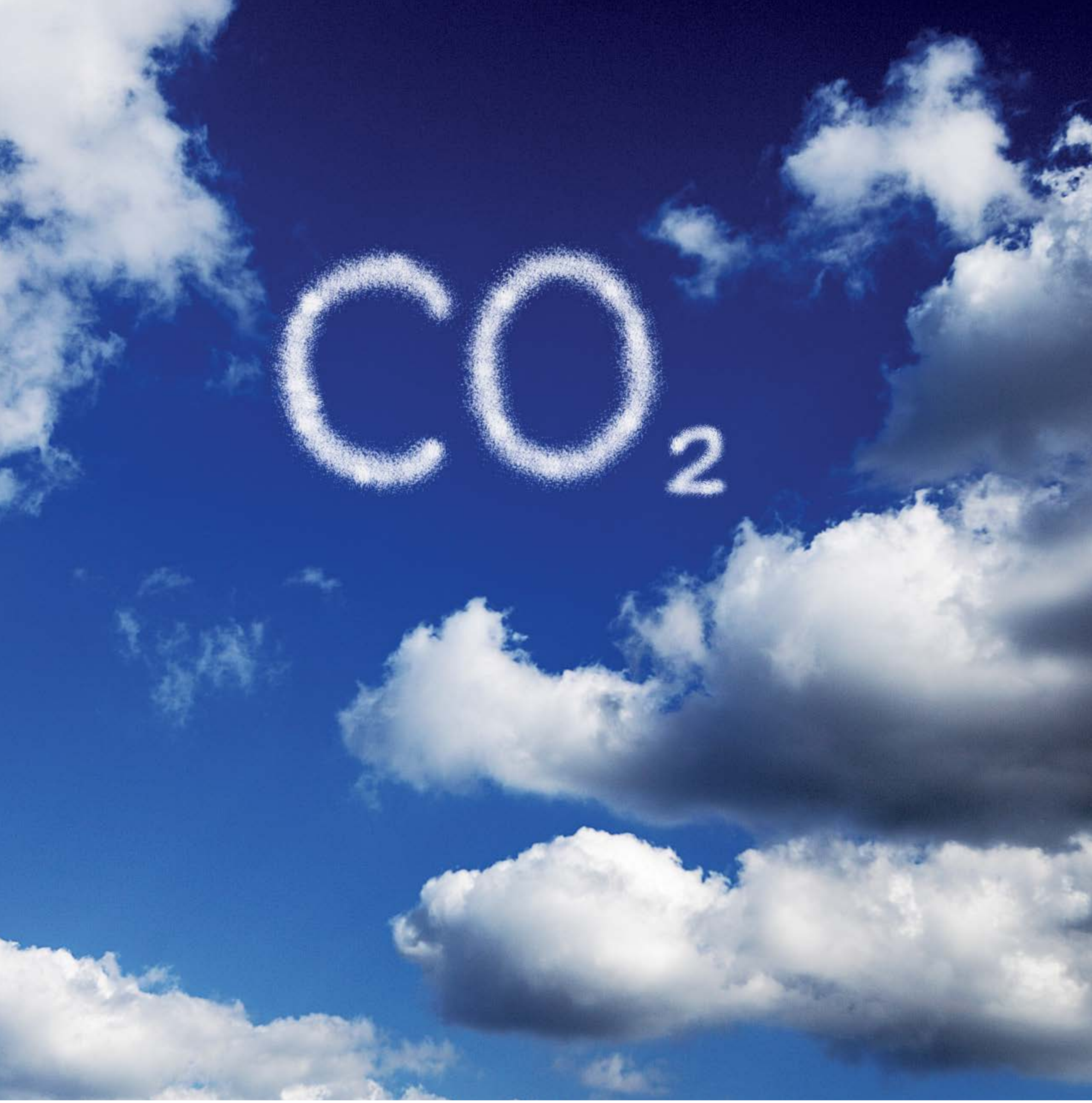
THE CARBON REMOVAL DEBATE

Asking Critical Questions About Climate Change Futures

Matthew C. Nisbet

INSTITUTE *for* CARBON REMOVAL
LAW AND POLICY



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Foreword

Removing carbon dioxide from the atmosphere must now be considered an essential component of humanity's response to climate change. Not all forms of carbon removal are, though, created equal. Much work is needed for society to sort through carbon removal's complex options, opportunities, and costs.

In this report commissioned by the Institute for Carbon Removal Law and Policy, communication scholar Matthew Nisbet looks at how it is that carbon removal has suddenly appeared on the climate policy agenda, why the entire field needs additional scrutiny, and how to build a better carbon removal conversation. Nisbet explains that carbon removal at the kinds of scales imagined by computer-based forecasts of climatic futures remains an untested and unproven proposition. Even so, the potential of carbon removal is already shaping the way humanity understands climate change and what constitutes reasonable action. More engineering and physical science research may, notes Nisbet, help remove some of the uncertainties when it comes to the roles that carbon removal might play in tackling climate change. In particular, research can help with the "right-sizing" of particular carbon removal approaches. Research will also, though, produce more political and social contestation. The future for carbon removal will depend as much on how and where this contestation is given productive shape as on the development of new technologies.

The closing section of the report discusses how funding that provides dedicated time for journalists and experts to dig into the complexities of carbon removal along with utilization of existing models for the engagement of publics in technological decision-making can improve the carbon removal debate. The Institute for Carbon Removal Law and Policy is committed to shining a light on and helping to cultivate these kinds of best practices. We welcome engagement with our work at our website: **www.carbonremoval.info**.

— Wil Burns and Simon Nicholson,
Co-Directors of the Institute for Carbon Removal Law and Policy

Preface

In recent years, the Intergovernmental Panel on Climate Change (IPCC) has been tasked by United Nations policymakers to assess hypothetical pathways to limit global temperature rise to levels consistent with the goals established by the 2015 UN Paris treaty. To do this, the IPCC surveyed research that uses computer-generated models to simulate hypothetical futures capable of meeting politically determined objectives.

Among the identified pathways in the 2018 IPCC report for keeping warming below either 2.0°C or 1.5°C, almost all require the deployment of still speculative carbon removal and storage methods, also referred to as "negative emissions technologies." Yet most carbon removal methods, such as bioenergy and carbon capture with storage or direct air capture remain at the preliminary research and assessment stage, with a great deal of uncertainty over their technical feasibility, social acceptability, cost, and associated impacts.

Critics argue that the reliance on unproven carbon removal methods to fulfill climate policy goals creates a false sense of complacency about the need for an immediate and aggressive transition away from fossil fuels. This maintains the political illusion that national leaders remain committed to the ambitious temperature targets established as part of the UN Paris treaty. As experts raise considerable doubts about the feasibility of carbon removal technologies, they have also called for a more honest public debate about the contestable assumptions involved in IPCC assessments, and the relatively invisible function of scenario modelling and carbon removal methods in current policy debate.

To inform the questions that need to be asked, Section 1 of this report details the role of the IPCC in providing input to policymakers and the arguments in favor of pursuing carbon removal methods. Section 2 briefly explains three of the most prominent carbon removal methods discussed in policy circles today, why BECCS in particular plays an outsized role in IPCC reports, and the arguments by critics warning of their uncertain nature. Section 3 describes the process by which key uncertainties about the feasibility of achieving ambitious global temperature targets were ignored by policymakers at the UN Paris meetings. Section 4 describes the central function that constructive disagreement and public dialogue must play in making responsible decisions about carbon removal methods.

1. Framing Climate Change Success

At the 2015 Paris climate summit, 197 nations pledged to keep global temperature rise to "well below" 2°C above pre-industrial levels and to strive to remain below 1.5°C. But even before the Paris meetings began, reported *Nature* magazine, some experts believed the society-wide transformations necessary to achieve the Paris Agreement's proposed 2°C target were "so optimistic and detached from current political realities that they verge on the farcical." If each of the countries involved in the UN treaty followed through on their initial pledges to cut emissions, the eventual temperature rise this century would be greater than 3°C.[1]

An optimistic reading of the Paris Agreement is that it represents an important foundation for coordinated greenhouse gas emissions abatement efforts that will strengthen through time. Since 2017, however, global CO_2 emissions have been growing, rather than declining. Most of the growth is driven by energy-hungry Asian nations which in seeking to expand their economies and improve the standard of living for billions of people, are investing heavily in the construction of new coal-fired power plants.[2] But even in Germany, which has made unprecedented gains in the deployment of solar and wind power, the country will fail to reach its 2020 target to reduce emissions by 40 percent of 1990s levels.[3] Meanwhile, the Donald J. Trump administration intends to withdraw the U.S. from the Paris treaty, and has implemented policies to expand domestic fossil fuel production and consumption.[4]

Following the 2015 Paris summit, the UN invited the Intergovernmental Panel on Climate Change (IPCC) to assess hypothetical pathways to achieving the proposed temperature targets and to estimate the consequences of failure. The IPCC authors relied on research that used Integrated Assessment Models (IAM) to estimate these pathways, blending scientific understanding of the earth system with a variety of societal factors related to population growth, the economy, human behavior, and energy use. The models are used to answer what-if questions about the future: What if mitigation technologies like solar power, wind power, and nuclear energy prove too costly or face political opposition, preventing their widespread deployment? What if a high global carbon price were adopted, thereby accelerating the shift away from fossil fuels? And most notably for the purposes of this report, what if technological options existed for removing CO_2 from the atmosphere, buying nations more time to cut their emissions?[5]

The request from the UN reflected a relatively new role for the IPCC and the researchers on whose work they rely. Following a shift toward emissions target-based scenarios in the lead-up to the IPCC's Fifth Assessment Report in 2014, researchers were increasingly adopting a "solution-oriented" mode, using computer-generated models to simulate hypothetical futures capable of meeting politically-determined goals. The main criteria for assessing the likelihood of various pathways was technical feasibility, rather than

also weighing social and political factors.[6] In doing so, models which had originally been designed for exploratory research were transformed by the IPCC into policy decision-making tools. "The use of models had shifted from being about showing what level of emissions (and hence warming) different future development scenarios would result in, to determining what technology choices and policies are required to achieve a specific warming 'target'," write geographer Kate Dooley and colleagues.[7]

Models which had originally been designed for exploratory research were transformed by the IPCC into policy decision-making tools.

Drawing on these modeling efforts, the IPCC authors of the resulting 2018 "Global Warming of 1.5°C" report estimated that global temperature, which had already risen about 1°C above pre-industrial levels, was likely to reach 1.5°C sometime between 2030 and 2052. In order to have a chance of meeting the 1.5°C goal, CO_2 emissions would need to be cut 45% by 2030, with the world achieving "net zero" emissions by 2050. Failing to meet the 1.5°C target, warned the IPCC authors, would result in an estimated $50 trillion in global damages from climate change by as early as 2040, including impacts such as extreme storms, coastal flooding, drought, and lethal heat waves that collectively would endanger hundreds of millions of people.[8]

Among the identified pathways for keeping warming below 1.5°C, only a handful assessed in the 2018 IPCC report relied exclusively on efforts to reduce or "mitigate" greenhouse gas emissions from human activities, whereas the great majority required both mitigation and the deployment of carbon removal and storage methods, also referred to as "negative emissions technologies" (NETs). By replacing the use of fossil fuels with cleaner energy options, mitigation-focused technologies such as solar power, electric cars, or nuclear energy decrease the amount of heat trapping pollution released into the atmosphere from the burning of fossil fuels, slowing temperature rise. Carbon removal and storage methods, in contrast, are designed to clean up already existing CO_2 pollution in the atmosphere, allowing a greater amount of solar radiation absorbed by the Earth to escape back into space, thereby lowering average global temperature.[9]

Removing CO_2 pollution and storing it underground or in other reservoirs can have the same impact on combatting climate change as preventing an equal amount of CO_2 from being emitted, argue proponents. Approximately 20–40% of annual greenhouse gas emissions today come from sources such as agriculture and transportation that over the next few decades will be exceedingly difficult to eliminate. There are major technological challenges to decarbonizing these sectors, but also social obstacles. For example, not only are flying, driving, and meat consumption likely to increase over the next few decades in wealthy countries, the rate of increase will be even greater in developing nations, as rising incomes among billions of people enable a more Western-style standard of living. [10] The advantage of pursuing carbon removal strategies is that stopping heat trapping CO_2 pollution from transportation, agriculture, and other sectors, does not require that human-caused emissions cease all together, but that the "net" total of emissions is less than or equal to the amount captured and stored by natural and man-made "sinks."[11]

2. Speculative Technologies

For these reasons and others, almost all of the pathways in the 2018 IPCC report for meeting the temperature goals established at the UN Paris meetings rely on CO_2 removal and storage technologies that by 2050 remove approximately 10 gigatons of CO_2 out of the atmosphere annually (a sum equivalent to 20% of all global CO_2 emissions today), and by 2100 remove 20 gigatons annually (equivalent to 40% of current emissions). By optimistically relying on carbon removal methods in their projections, researchers were also able to model pathways in which a mid-century "overshoot" of global temperature targets could hypothetically occur, followed by a return to lower global temperatures later in the century, theoretically buying more time for world society to shift away from fossil fuels.[12] However, overshooting a 1.5˚C threshold, warned the IPCC authors, would also likely come with severe consequences, resulting in the die-off of almost all coral reefs, irreversible species and biodiversity loss, unprecedented economic damages, and threats to the lives and welfare of millions of people.[13]

The various options available for carbon removal differ in how much CO_2 they can remove and at what cost, their specific risks and co-benefits, and the process by which carbon is captured, stored, and/or repurposed. Because of their limits and diversity, carbon removal methods cannot be considered separately from traditional mitigation and adaptation options nor without comparison to other negative emissions technologies, since in most cases specific carbon removal methods either complement or compete with multiple other options.[14]

Figure 1 summarizes the most prominent forms of carbon removal methods, categorizing them according to where they would be implemented (e.g. either on agricultural land or in coastal waters etc.). In doing so, the figure highlights that some methods compete with each other because they would occupy the same physical space. For example, afforestation/reforestation competes with most forms of bioenergy with carbon capture and storage (BECCS) because land devoted to forests cannot be used to grow bioenergy crops.[15]

Bioenergy with carbon capture and storage

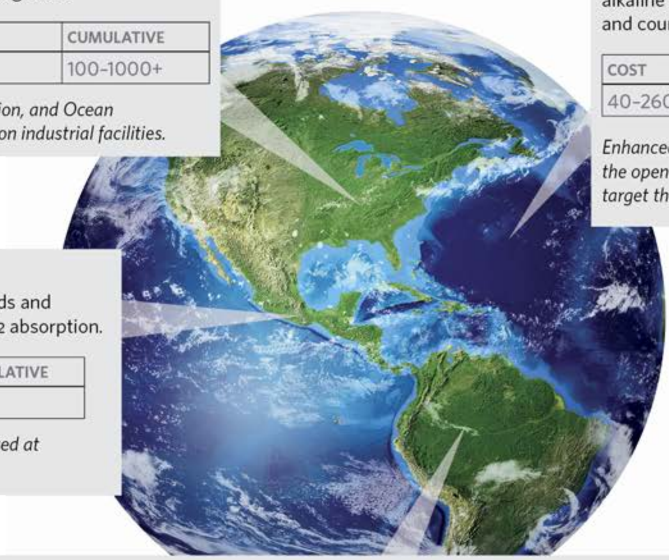
Although a range of carbon removal methods exist, almost all IPCC scenarios for meeting either a 1.5°C or 2.0°C target rely on the deployment over the next few decades of tens of thousands of bioenergy with carbon capture and storage (BECCS) plants, in the hope that the technology could account for approximately 10–15 gigatons of annual CO_2 removal by 2100 (more than half of the carbon removal capacity that the IPCC estimates is needed). Yet BECCS technology remains at the preliminary research and assessment stage, with a great deal of uncertainty regarding technical feasibility, cost, risks, and social acceptability.[16]

Figure 1: Prominent methods of carbon removal

Carbon removal methods can be compared based on cost, potential rate of carbon removal, and potential for total, cumulative storage of carbon dioxide, as well as in terms of side effects and risks. Estimates for some prominent methods' cost and potential are given below.

COST	Cost of removing one ton of CO_2 and sequestering it ($/t$CO_2$)
RATE	Amount of CO_2 that could be removed per year by 2050 (GtCO_2/yr)
CUMULATIVE	Total amount CO_2 that could be removed in this century (GtCO_2)

Note that carbon removal methods that use the same kind of space, such as arable land, could either compete with or complement one another, depending on the details of location, implementations, etc.



INDUSTRIAL FACILITIES

DACCS (Direct Air Capture with Carbon Storage): Capture CO_2 from the atmosphere by chemical means and sequester it underground.

COST	RATE	CUMULATIVE
100-300	0.5-5	100-1000+

BECCS, Enhanced Mineralization, and Ocean Alkalinization would also rely on industrial facilities.

OPEN OCEANS

OCEAN ALKALINIZATION: Spread lime or other alkaline substances over the ocean to absorb CO_2 and counteract ocean acidification.

COST	RATE	CUMULATIVE
40-260	N/A	N/A

Enhanced Mineralization could also be conducted in the open ocean. Proposals for ocean fertilization also target the open ocean.

COASTAL AREAS

BLUE CARBON: Manage coastal wetlands and seagrass meadows to enhance their CO_2 absorption.

COST	RATE	CUMULATIVE
N/A	N/A	N/A

Ocean Alkalinization could also be conducted at coastal sites.

ARABLE LAND

BECCS (Bioenergy with Carbon Capture and Storage): Grow or collect biomass to produce biofuels, heat, or electricity and then capture and sequester the CO_2 released in the process

COST	RATE	CUMULATIVE
100-200	0.5-5	100-1170

BIOCHAR: Grow or collect biomass, convert it to charcoal, and bury it.

COST	RATE	CUMULATIVE
30-120	0.5-2	78-477

SOIL CARBON SEQUESTRATION: Increase soils' capacity to absorb carbon through practices such as no-till agriculture and crop rotation.

COST	RATE	CUMULATIVE
0-100	2-5	104-130

AFFORESTATION/REFORESTATION: Plant or restore forests, which absorb and hold carbon as they grow.

COST	RATE	CUMULATIVE
5-50	0.5-3.6	80-260

ENHANCED MINERALIZATION: Spread rock powder on land, where it reacts with CO_2 in the air, or expose it to CO_2-rich fluids.

COST	RATE	CUMULATIVE
50-200	2-4	100-367

Source: Morrow, David R., Holly Jean Buck, William CG Burns, Simon Nicholson, and Carolyn Turkaly. "Why Talk about Carbon Removal?." Carbon Removal Briefing Paper (Washington, DC: Institute for Carbon Removal Law and Policy, American University), DOI/10.17606/M6H66H (2018).

BECCS uses agriculture residues, municipal waste, algae, forest residues, and the cultivation of crops to produce electricity, liquid fuels, and/or heat. The CO_2 generated is captured, transported, and stored underground (a process called geologic sequestration) or recycled in the manufacture of various products.[17] BECCS therefore serves in the dual role of creating sinks for carbon (in the form of bioenergy plantations) and as a source of net-zero energy production (in the form of burning bioenergy crops and locking away the emissions).[18]

BECCS features so heavily in integrated assessment models (IAMs) because its estimated cost is low relative to other anticipated options and because modelers are still developing methods for representing direct air capture and other carbon removal methods in their projections.[19] But to meet the optimistic BECCS assumptions of modelers, by some estimates, biomass for fuel would need to be grown across 740 million–1 trillion acres of land, a combined area larger than India, encompassing 40 percent of current global cropland. To facilitate this historically unprecedented shift in land use, and to prevent food shortages, most IPCC models also assume technological breakthroughs that enable vast improvements in agricultural yield, major reductions in food waste, and the mass adoption of plant-based diets. Critics justifiably argue that these assumptions are not only unrealistic, but also risky. BECCS deployed at the scale needed to meet a 1.5°C goal—that is, if all or a preponderance of the carbon removal called for in the models relied on by the IPCC were sourced from BECCS—could result in damage to biodiversity equal to that which policymakers are hoping to avoid from global warming, create demand for water equivalent to that used for agricultural irrigation globally, and conflict with land rights and other environmental justice priorities.[20]

There has also been little analysis of the transportation challenges related to the rapid scale up of bioenergy, which either needs to be grown, burned, and sequestered near major cities and industries, or transported long distances by truck, rail, or ship, a process that is both costly and carbon polluting. Some analysts argue that the most likely future involves the creation of an elaborate supply chain for bioenergy, with crops grown in developing countries and transported to be burned in the major economies of Europe, North America, and Asia, followed by further transportation to dispose of the resulting CO_2.[21] For skeptics like the ethicist Clive Hamilton, "there is something deeply perverse in the demand that we construct an immense industrial infrastructure in order to deal with the carbon emissions from another immense infrastructure, when we could just stop burning fossil fuels."[22]

Although highly speculative, BECCS as a main option for meeting ambitious temperature targets remains politically appealing since IPCC scenarios derived from IAMs have a strong optimistic bias towards new carbon removal technologies that materialize sometime in the future. Modelers assume (and policymakers hope) that the discounted costs of these uncertain methods will eventually be less than the current cost of relying on existing mitigation options to rapidly transition away from fossil fuels. In this case, argue climate scientists Kevin Anderson and Glen Peters, the imaginary technology of BECCS provides a false sense of complacency relative to the continued reliance on fossil fuels while maintaining the illusion that countries remain committed to the temperature targets established as part of the UN Paris Agreement. Maintaining this fiction, they assert, is far more politically appealing than pursuing the much more contentious route of enacting policies aimed at rapid and deep cuts in emissions.[23] The risk of a moral hazard is high: The massive deployment of BECCS may eventually prove possible, but it will take decades to know for sure. If the challenges prove too great, "future generations may be stuck with substantial climate change impacts, large mitigation costs, and unacceptable trade-offs" write climate scientists Christopher Field and Katharine Mach.[24]

Direct air capture and storage

Direct air capture and storage (DACCS) is a second carbon removal method that has generated significant news coverage since the 2015 Paris Agreement. Researchers at Carbon Engineering, a Canadian firm that operates a small-scale, pilot CO_2 capture plant in British Columbia, estimated that their patented process would be able to pull CO_2 out of the air at a cost between US$94 and US$232 per ton of CO_2, depending on the details of implementation and assumptions about financing and energy costs.[25] This estimate, if accurate, is a major advance over previous projections which had priced the cost of various schemes between US$640–819 per ton of CO_2.[26] But as *Nature* magazine reports, the cost per ton "is still likely to remain above the market price of carbon for the foreseeable future," and will depend heavily on regional and national policy measures that provide carbon credits, tax carbon, or provide tax incentives, measures that have proven politically difficult to implement.[27]

Surveys across countries also reveal a general public that, although mostly unaware of various carbon capture technologies, voice reservations when asked their opinion, perceiving the technology as "unnatural" and "risky." Rather than assuage public reservations, providing more information about the technologies tends to strengthen, rather than lessen, opposition.[28] Public opinion is also likely to vary by the proposed uses of DACCS. In 2019, Occidental Petroleum and Chevron invested in Carbon Engineering, with plans to build a full scale DACCS plant in Texas to provide CO_2 for enhanced oil recovery. In this process, CO_2 extracted from the atmosphere is injected into oil fields to scrape out more oil than possible using conventional methods. Several environmental groups strongly oppose the use of DACCS on behalf of enhanced oil recovery, since they argue it "greenwashes" fossil fuel development as "carbon neutral."[29]

Moreover, in locations where conventional carbon capture and storage trials have taken place specific to fossil fuel power plants, the projects have been met with opposition by local activists, suggesting that future debates over the large scale deployment of direct air capture may play out in similar ways.[30] In the case of DACCS, local opposition is likely to be especially intense given the unprecedented amount of land needed to operate a full-scale plant. For example, in the "liquid solvent system" design for direct air capture, the array of "contactors" that capture air from the atmosphere must be arranged around a centralized regeneration facility where the air is heated, filtered, and compressed producing CO_2 to be repurposed, transported and/or sequestered. Powering such a system, like all DACCS designs, necessitates a dedicated source of electricity generation with the most likely option a natural gas plant combined with solar and/or wind generation.[31]

Given these requirements, the authors of a 2019 National Academies of Science, Engineering, and Medicine (NASEM) report estimate that the total footprint of a liquid solvent system plant capable of capturing 1 million tons of CO_2 per annum at between 14,500–25,500 acres, or roughly 22–40 square miles, a gargantuan-sized tract that at the low-end is *433 times larger* than the average U.S. natural gas plant. Deploying just 100 liquid solvent system-designed plants would take up a landmass equal to or greater than the size of Delaware. For the alternatively designed "solid sorbent system" DACCS plants, the NASEM authors estimate a land footprint at between 500–2,450 acres or roughly 0.8–3.8 square miles, a comparatively smaller land mass that is still 17 to 81 times larger than today's average natural gas plant.[32]

Natural climate solutions

In contrast to DACCS and BECCS, one set of prominent carbon dioxide removal methods, formally referred to as "terrestrial carbon removal and sequestration," have for decades received consideration for their climate benefits. These so-called natural climate solutions include "reforestation," the restocking of existing forests and woodlands; "afforestation," the planting of new forests where none previously existed; and "soil sequestration" through more sustainable agricultural practices.[33] Agriculture, forestry, and other types of land use currently account for 23% of human GHG emissions, concluded the 2019 IPCC "Special Report on Climate Change and Land." At the same time, natural land processes currently absorb carbon dioxide equivalent to almost a third of CO_2 emissions from fossil fuels and industry. Therefore, better land management can and should be a vital component of any effective approach to climate change.[34]

Yet, as the IPCC report and other expert assessments emphasize, decades-long efforts to promote the widespread adoption of sustainable forestry and agricultural practices have proved elusive, despite the well-financed efforts of international conservation groups. Natural climate solutions are also not guaranteed to be permanent, with wildfires, land use, or other damage to ecosystems releasing heat trapping pollution back into the atmosphere.[35]

Moreover, the storage of CO_2 by natural climate solutions methods would also compete directly with the demand for land created by DACCS and BECCS, and introduce a similar set of social justice questions.[36] In particular, the populations of less developed countries along with rural publics living in wealthier nations will be asked to bear almost all of the risks related to possible economic and social dislocations on behalf of the urban populations of North America and Europe who through their energy consumption are the main source of the carbon intended to be sequestered from afforestation/reforestation and more sustainable agricultural practices.[37]

Decades-long efforts to promote the widespread adoption of sustainable forestry and agricultural practices have proved elusive, despite the well-financed efforts of international conservation groups.

3. Legitimating the Unbelievable

As experts raise considerable doubts about carbon removal technologies, they have also called for a more honest public debate about the contestable assumptions involved, and the broader influence that IAM modelling holds over policy debate. The rapid incorporation of carbon removal schemes into future climate change scenarios emerged in the years following the 2007 IPCC Fourth Assessment Report (AR4). Scientists responded to policymaker requests for research demonstrating the technical feasibility of keeping end-of-the-century global temperature rise below 2°C warming, incorporating negative emissions technologies into most of the IAMs that informed the 2014 IPCC Fifth Assessment Report (AR5).[38]

Drawing on interviews conducted with IAM specialists, Dooley and colleagues conclude that modelers accept responsibility for communicating with policymakers about the assumptions that shape their work. But as one interviewee acknowledged, even though "we do our best" to convey the complexities and trade-offs inherent in model assumptions, this is often "lost in translation." Qualifications included in the AR5 Summary for Policymakers, for example, emphasized that 2°C scenarios relied on the deployment of NETs.

But in the lead-up to the UN Paris climate summit, these caveats were largely ignored by official statements from policymakers. The text of the Paris Agreement calls, in Article 4(1), for countries to "achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century." This, however, is the limit to the discussion of carbon removal in the final text of the international treaty. It is unclear, conclude Dooley and colleagues, whether the absence of explicit reference to carbon removal is due to a lack of understanding by policymakers or a deliberate choice to avoid a contentious issue. Either way, the adoption of the 2°C and 1.5°C targets at Paris functioned as the tacit "acceptance of large-scale NETs without any critical policy or public debate over potential impacts and lock-in effects," they write.[39]

The IPCC has performed an "important legitimating function for the speculative technology of BECCs," argue the sociologists Silke Beck and Martin Mahony. The IPCC pulled carbon removal technology "into the political world, making previously unthinkable notions—such as overshoot and collapse mainstream and acceptable." Technical feasibility was given priority over questions of the societal desirability of various carbon removal methods. As a consequence, scientific claims made by the IPCC about the future have become political interventions, shaping the potentially irreversible path of societal decisions.[40]

By including the speculative potential of carbon removal methods in their models, IPCC scientists have encouraged policymakers and investors to move forward with plans to develop the technologies, argue Beck and Mahoney. Carbon removal

options like BECCS are currently discussed in international policy circles and in journalistic coverage as if they are already an inevitable part of our future, a conversation that has skipped past the question of whether they should be relied on in the first place. "In less than a decade, negative emissions went from an afterthought to being absolutely essential to international climate policy," observes political scientist Roger Pielke Jr. "No government had actually debated the merits of BECCS, there were no citizen consultations, and very little money was being devoted to research, development, or deployment of negative emissions technologies. Yet there it was at the center of international climate policy."[41]

Climate policy experts Tim Kruger, Steve Rayner, and Oliver Geden argue for excluding carbon removal technologies from IPCC scenarios until there is sufficient evidence of their viability. "To model what you want to happen, rather than what there is evidence to happen, is to lose the thread of reality," they write. Not only must the technical and economic feasibility of carbon removal technologies be demonstrated, so too must their political feasibility. To be deployed, a technology must eventually achieve acceptance among key decision-makers, interest groups, and influential segments of the public, especially those at the local level. For example, Germany currently has the technical and economic capability to build new nuclear power plants as a means to cut their emissions, note Kruger and colleagues, but political opposition makes such capabilities moot.[42]

Given the perceived urgency of climate change, carbon removal methods have been talked about only in the most ambitious and grandiose of schemes, rather than in a more useful frame of "right-sized" approaches. "Many candidate [carbon removal] technologies have the potential to be the foundation for strong enterprises, capturing many millions of tons of carbon dioxide per year, in locations where each approach makes sense technically and economically, with a favorable mix of co-benefits and side effects," note climate scientists Field and Mach. "It is at much larger scales (billions of tons of CO_2 per year) that the technologies warrant concern."[43]

The goal of experts and advocates should not be to sell, message, or build support for carbon removal technologies, but rather to push a discursive "reset button" that shifts the focus to a diversity of right-sized approaches that draw on a plurality of perspectives. The emphasis should be on "conditionality," in which every option can be "done badly or well." In a world that necessitates tradeoffs, for every option that an expert or advocate deems problematic, they must ask: under what circumstances could they accept its deployment as a companion to the deployment of an option they do like? "We must remind ourselves that we want solutions to work. It is not enough for us to identify what is wrong with a strategy as it is first proposed," the physicist Robert Socolow argues. "We must ask ourselves: what changes would be necessary for the strategy to become acceptable? How might the world get from here to there?"[44]

Research on carbon removal should move forward since the technology may prove useful, a 2018 report from the European Academies Scientific Advisory Council (ESAC) concluded, but NETs are not a "backstop" or "silver bullet" replacing the need for deep and rapid emissions reductions. Given their uncertainties, carbon removal technologies should be excluded from future European decarbonization scenarios, the ESAC authors recommended.[45] According to the authors of the 2019 NASEM report, the U.S. should "launch a substantial research initiative to advance negative emissions technologies (NETs) as soon as practicable." Considerable constraints on various carbon removal methods mean they are likely to fall well short of IPCC projections, but some of these constraints could be overcome by way of additional research, the committee optimistically concluded.[46] Technically oriented research alone, though, is not enough. Carbon removal needs broader and more effective societal consideration. This means investing in debate.

4. Investing in Debate

Given the centrality of carbon removal methods to achieving the temperature targets agreed to as part of the 2015 UN Paris Agreement, it is essential for journalists and experts to call greater attention to relevant uncertainties and to scrutinize their social and political implications. How should research and innovation take place? What might be the unintended consequences? Who gets to decide the deployment of carbon removal technologies or the actions to address the problems they may create? Which values, interpretations, and worldviews matter? Will carbon removal technologies be deployed to benefit the public interest or on behalf of special interests? How should this conversation, and the disagreement that ensues, be structured? What are the principles and criteria that should apply?

Much of the current enthusiasm about carbon removal methods reflects a longstanding tendency to favor "techno-fixes" as a method to bypass politics. If it is too contentious and costly to rapidly transition away from fossil fuels, why not invent new technologies and methods that bypass the politics, innovations that are allegedly "just around the corner," or "in the near future"?[47] Yet overlooked in this line of thinking is that the pursuit of planetary-wide carbon removal will likely introduce its own set of intractable controversies. Building a vast industrial carbon capture, bioenergy, or natural climate solutions infrastructure to replace a fossil-fuel infrastructure that also competes with agricultural production and poses threats to land rights and local ways of life is a strategy guaranteed to produce more politics, not less.

The authors of the 2019 NASEM report suggest that the financing of a large-scale carbon removal research program may be able to reduce many of the current constraints, uncertainties, and challenges to deployment. But more research, as the science policy scholar Dan Sarewitz and others have documented, can intensify disagreement, since new evidence is often sufficiently tentative enough to indefinitely support the values-based arguments of competing sides. All-too-familiar clashes are likely to surface over the proper role of markets versus government, international governance versus national autonomy, fairness and equity, and the balancing of benefits against precaution in the face of risks, uncertainty, and costs.[48]

A push back against a prevailing discourse of "climate deadline-ism" must also be a part of this questioning process. The translation by the UN and the IPCC of what counts as dangerous versus acceptable climate change in terms of highly improbable end-of-century temperature targets has led to a misleading narrative emphasizing a deadline of a decade or so after which policy interventions "will be too late" to avert catastrophe, argues geographer Mike Hulme.[49] The resulting declaration by some activists and journalists of a "climate emergency," not only implies that "we will remain in a quasi-permanent state of emergency; it also obscures much of what

actually matters for human well-being and ecological integrity," writes Hulme. "Carbon metrics are only a proxy for global temperature, which is only a proxy for regional weather, which is only a proxy for human well-being, which depends on innumerable other factors for its achievement and maintenance."[50] Climate emergency thinking short-circuits the ability to engage in the type of challenging deliberations that are needed about carbon removal methods, casting discussion of carbon removal in terms of the most ambitious and grandiose of schemes, rather than in a more useful frame of "right-sized" approaches.

Facilitating disagreement

Somewhat paradoxically, only by way of critically motivated journalistic reporting and expert analysis can public trust in climate science, the IPCC, and climate removal methods be maintained. Rather than portray science, scientists, and engineers as truth's ultimate custodians, journalists and experts writing across public forums must reveal for readers how research and engineering really works. When controversies related to bias, uncertainty, or conflicts of interest emerge, or when a high-profile study purporting the promise of a carbon removal method is later contradicted by a subsequent study, policymakers and attentive publics will be more likely to be able to judge when such behaviors are outliers or the norm. Just as peer-review and other established norms within science and engineering serve as partial correctives to such failures, journalists and experts as "knowledge critics" can and should fulfill a similarly vital and complementary role.[51]

Moreover, numerous social science studies demonstrate that on complex decisions such as those involving carbon removal, if consensus about the promise of various technological options are closely defended to the exclusion of dissenting voices, individuals including experts are likely to make poorer decisions and think less productively. In contrast, exposure to dissent, even when such arguments may prove to be wrong, tends to broaden thinking, leading individuals to think in more open ways, in multiple directions, and in consideration of a greater diversity of options, recognizing flaws and weaknesses in positions.[52]

Much of the current enthusiasm about carbon removal methods reflects a longstanding tendency to favor "techno-fixes" as a method to bypass politics.

But facilitating constructive disagreement about carbon removal methods depends greatly on new sources of philanthropy that make a sustained commitment to the organizations, forums, thinkers, and journalists capable of bringing to light alternative problem framings and policy options. If well-qualified journalists and academics, for example, are provided by way of foundation- and government funding the time and resources they need to critically investigate the complexity of factors related to carbon removal methods, they are more likely to be able to bring to light novel narratives and alternative ways of thinking that fuse together new coalitions on behalf of politically feasible and technically realistic actions.

Well-designed fellowships, for example, also provide journalists and experts with training in how to promote their work, and with assistance in pitching projects to top publishers and/or other funders. Recent history suggests that top-selling books by fellowship-supported authors have the potential to alter the national conversation about climate change and energy. A two-year New America fellowship enabled *Rolling Stone's* Jeff Goodell to author the influential 2017 book *The Water Will Come: Rising Seas, Sinking Cities, and the*

Remaking of the Civilized World. A one-year New America fellowship supported New York magazine writer David Wallace-Wells as he wrote the 2019 best-seller *The Uninhabitable Earth: Life after Warming*. Such books not only directly influence the thinking of their readers, but by way of prominent reviews, profiles, public radio and podcast interviews, and numerous public events, the authors also reach opinion-leading audiences with novel critiques, ideas, and solutions.

Facilitating dialogue

Among the most important types of forums to invest in are those that bring together a relatively small group of experts, journalists, philanthropists, advocates, policymakers, and industrialists to debate ideas, share concerns, and connect over civil, cross-cutting conversations. A first step is simply to recognize and affirm shared values, beliefs, and goals. With this established, further dialogue can be structured in such a way as to encourage working together toward common ends that may be supported for different reasons.[53] For example, an environmentalist may favor investment in DACCS because of climate change, but a conservative may favor the same option because of concerns about maintaining economic growth and international competitiveness. Such motivations, for example, led to the inclusion in the 2018 U.S. Federal budget bill of tax credits for carbon capture and storage, which provided a market incentive for the construction in Texas of Carbon Engineering's first full-scale DACCS plant.[54]

Other important approaches to dialogue actively involve the public in the co-production of expert knowledge and in the discussion of policy options, a process that will be especially important given the significant opposition that large-scale carbon removal methods are likely to face at the local level. At many land grant universities, cooperative education in the form of agricultural extension and Sea Grant offices will be essential to knowledge co-production across rural areas of the U.S. and in developing countries.

The emphasis in these programs is on trust building and social learning, using existing university-affiliated infrastructures, networks, resources, and expertise to facilitate an iterative, two-way exchange of knowledge and perspectives. Expert advice and techniques on issues such as farming practices and land conservation along with information about risks, costs, and benefits of other relevant carbon removal methods are provided to local professionals and stakeholders. These groups in turn provide feedback to university representatives and experts on what kinds of carbon removal methods and practices are likely to work and to be socially acceptable. This process involves not only consulting the public about specific concerns, needs, and specialized knowledge, but also recruiting opinion-leaders and early adopters among these groups to influence their peers. In all, the networks maintained by university-based cooperative education programs offer tailor-made opportunities for scientists, experts, industry leaders, and their collaborators to engage in dialogue with a broad spectrum of publics.[55]

In related knowledge co-production approaches developed by sustainability science researchers, public consultation starts early with the identification of relevant research questions and lines of inquiry that integrate the needs and questions of relevant stakeholders and policymakers. This type of early "upstream engagement" often takes time. Yet, if successful, as the research is eventually produced, at the final "downstream" stage it will be perceived as having greater value by policymakers and the public, and therefore be easier to communicate and translate.

In a leading example, the George W. Mitchell Center for Sustainability Solutions at the University of Maine has developed elaborate upstream consultation methods in studying state-wide decisions and practices related to sustainable forest and timber industry management, and in

promoting "soil health" farming practices related to cover cropping, reducing tillage, and biochar. Mitchell Center projects involve physical scientists, engineers, economists, anthropologists, and communication scholars working together to understand the physical, social, and human dimensions of sustainability issues. This interdisciplinary process extends from the campus into communities, organizations, and state agencies, as Maine residents, professionals, and stakeholders are consulted early on in the problem definition process through the implementation stage. This two-way interaction enhances expert understanding while building relationships of trust and networks of communication.[56]

Ultimately, in each of these important investments and others, effective decisions about carbon removal methods will depend on recognizing alternative interpretations and rival positions, then finding ways to negotiate them constructively, forging new narratives and ways of thinking. Insights are needed from a variety of disciplines, experts, and publics. Leaving out perspectives not only weakens our ability to manage various methods of carbon removal, but also risks the loss of legitimacy and trust among crucial decision-makers and constituencies.[57]

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