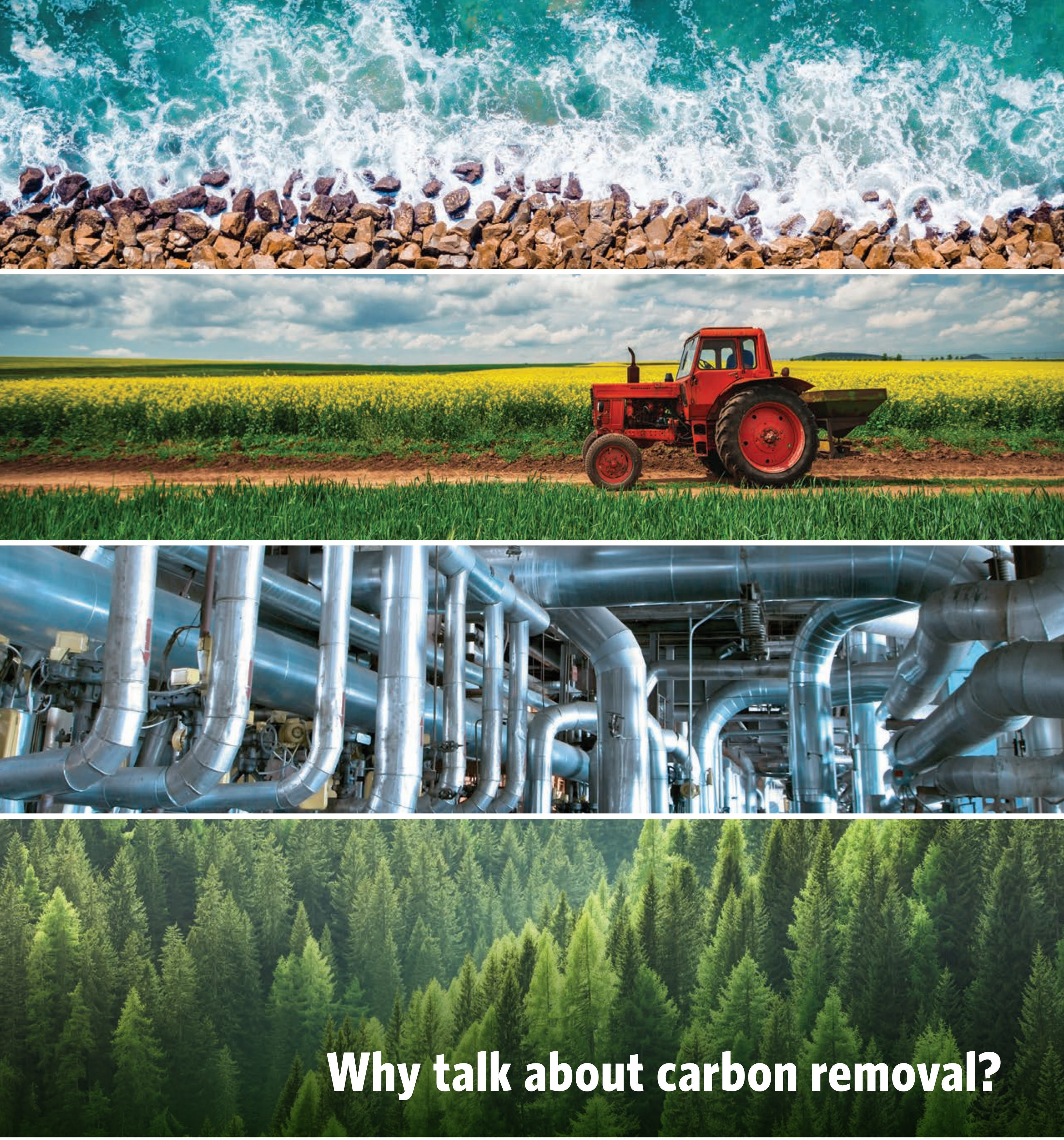

Why talk about carbon removal?

INSTITUTE *for* CARBON REMOVAL LAW AND POLICY

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Table of Contents

Abbreviations

AF/RF	Afforestation/Reforestation
BECCS	Bioenergy with Carbon Capture and Storage
CCS	Carbon Capture and Sequestration
CO_2	Carbon dioxide
DACCS	Direct Air Capture and Carbon Storage
$GtCO_2$	Gigatons (billions of metric tons) of carbon dioxide
IPCC	Intergovernmental Panel on Climate Change
NGO	Non-Governmental Organization
UNFCCC	United Nations Framework Convention on Climate Change
REDD+	Reducing Emissions from Deforestation and forest degradation in Developing Countries

Preface

Talk of removing carbon dioxide from the atmosphere is spilling out of scientific circles and into the realm of climate politics and policy. Civil society has a vital role to play in ensuring that this conversation is responsive to social needs and develops in constructive and appropriate ways. This report provides a starting point to help environmental and social justice non-governmental organizations (NGOs) engage in the growing conversation about carbon removal.

Section 1 of the report argues that the world needs to grapple seriously with large-scale carbon removal and long-term storage, exploring both the rationale for considering carbon removal and the associated risks and downsides. Section 2 provides a brief introduction to the range of options for large-scale carbon removal. Section 3 surveys the existing conversation in different domains, from academia to philanthropy to civil society. Section 4 considers the relationship between carbon removal and mitigation. Section 5 sketches a research agenda for assessing various approaches to carbon removal.

1. The Case for a Conversation about Carbon Removal

Removing carbon from the atmosphere is not a new idea in climate policy. Internationally, much time has already been spent working out rules for sink enhancement within the discussions of Land-Use, Land-Use Change and Forestry, as well as the mechanism for Reducing Emissions from Deforestation and forest degradation in Developing countries (REDD+). Carbon capture and sequestration (CCS), while not strictly speaking a form of carbon removal, has also been an ongoing topic of discussion following the 2005 special report on the topic from the Intergovernmental Panel on Climate Change (IPCC).

What Is Carbon Removal?

Carbon removal is the process of capturing carbon dioxide from the atmosphere and locking it away for decades, centuries, or longer. The various proposals for doing this take three main approaches: biological methods, which use forests, agricultural systems, and marine environments to capture and store carbon; geologic methods, which capture carbon dioxide by various means and store it underground or in rock; and carbon-utilization methods, which capture carbon dioxide and use it to produce long-lived products such as plastics or cement. While some of these methods are already in use or in development, the overall rate of carbon removal would need to be scaled up enormously to significantly affect atmospheric concentrations of carbon dioxide.

The nature of the discussion has shifted dramatically in the last few years, however, as the scale of the carbon removal challenge becomes apparent. The past decade has seen a flurry of research on meeting ambitious climate policy goals, driven by heightened levels of public and policy concern about climate change and by political breakthroughs like the Paris Agreement. It is becoming clearer that even modest increases in the global average temperature can have dramatic implications for human and planetary wellbeing. It is also becoming clearer that humanity's actions to date have been insufficient to avert large-scale changes to the climate system and that responding to climate change becomes more difficult as time passes. There may still be pathways to meeting ambitious climate targets that rely exclusively or almost exclusively on traditional forms of mitigation—switching from the burning of fossil fuels to renewable sources of energy and changing land-use patterns to prevent stored carbon from entering the atmosphere.[1] Increasingly, though, research has been suggesting that humanity will have to scale up its carbon removal efforts dramatically over the coming century.[2] By the time the IPCC had begun its work on a Special Report on Global Warming of 1.5°C, many climate policy analysts had concluded that meeting that aspirational target—as well as the internationally agreed 2°C target—would require clawing back billions of tons of carbon dioxide (CO_2) from the atmosphere by 2100.[3]

Because scaling up carbon removal will take decades,[4] the time to begin thinking seriously about how to do that is now. And because the technologies and practices for removing carbon have important social, political, and environmental consequences, the conversation about which ones to use and when and how to use them should be broad and inclusive. This section lays out the case for removing carbon on a large scale and sketches the limitations and downsides of doing so.

The dominant scientific view is that carbon removal is necessary to avoid dangerous climate change

The Paris Agreement established the ambitious target of keeping warming "well below 2°C," along with an aspirational target of limiting warming to 1.5°C. Even 1.5°C of warming threatens the integrity of many ecosystems and threatens the lives and livelihoods of many people. Increasingly, achieving either goal appears to require stretching the carbon budget by removing large amounts of carbon dioxide from the atmosphere via "negative emissions technologies" or "NETs." It may even entail an "overshoot" of temperature targets, followed by a return to lower levels through carbon removal. Carbon removal may also allow societies to compensate for especially hard-to-decarbonize sectors, such as aviation.

Calculations in the IPCC's Fifth Assessment Report indicate, based on computer simulations, that meeting a 2°C target would require removing around 670 billion metric tons of carbon dioxide ($GtCO_2$) during this century (range 320–840 $GtCO_2$), with 10 $GtCO_2$ or so removed each year by the end of the century.[5] For context, current emissions are around 40 $GtCO_2$ per year—or the equivalent of roughly 50 $GtCO_2$ when one accounts for the forcings from other greenhouse gases. In short, the great majority of scenarios used to limit warming to 2°C or 1.5°C:

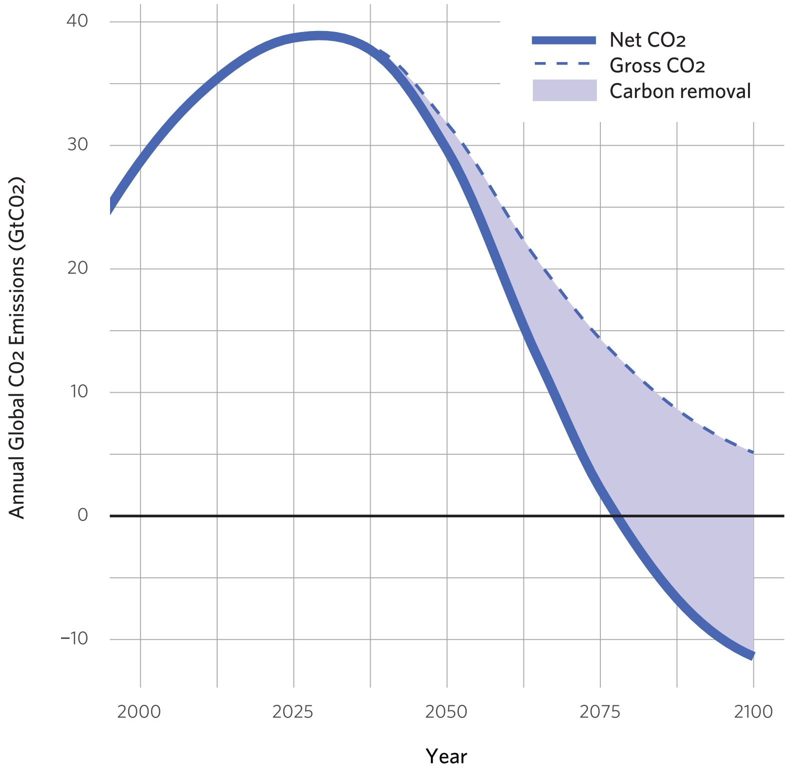
1. rely upon carbon removal at scales far beyond anything feasible today;
2. assume that net-negative emissions are reached around 2070 or earlier; and
3. indicate that carbon removal is pursued in earnest by the 2020s and 2030s, and removals reach a significant scale by 2050.

Figure 1, on page 6, depicts one such scenario. This illustrative example has global CO_2 emissions peaking around 2030, with carbon removal reaching the gigaton scale in the 2040s. While gross emissions of CO_2 (dotted line) decline quickly over they century, they do not reach zero. Carbon removal (light blue) increases significantly, reaching roughly 15 $GtCO_2$ by 2100, leading to net-negative emissions (dark blue line) by about 2080. The end result is an atmospheric CO_2 concentration in 2100 that is consistent with meeting the 2°C target.

Scientists have identified some scenarios in which the world holds warming below 2°C without large-scale carbon removal, although this becomes all but impossible if current emissions trajectories continue through 2030.[6] More recently, scientists have published a few scenarios that meet the 1.5°C target with very limited use of carbon removal, but these require dramatic progress in other kinds of ambitious mitigation efforts and expansion of forest land.[7]

The realization of the importance of carbon removal for meeting Paris targets has rippled through both the scientific literature and the press in the past few years. The academic literature on

Figure 1: Global CO2 emissions trajectory over the 21st century



This chart of CO2 emissions in an ambitious mitigation scenario illustrates one example of the role that carbon removal might play in limiting warming below 2°C. Note that in this particular scenario, global emissions become net negative by about 2080, even though gross emissions remain well above zero through the end of the century.

carbon removal has mushroomed in recent years, as documented by a recent systematic review of that literature.[8] The IPCC's special report on Global Warming of 1.5°C, released in October 2018, identifies carbon removal as crucial to limiting warming to 1.5°C, with the scale depending on the rate of emissions reductions.[9] A report by the European Academies' Science Advisory Council released in early 2018 concluded that the IPCC projections from their Fifth Assessment Report in 2013 and 2014 were over-optimistic, and that none of the proposed technologies would deliver negative emissions at the imagined scales.[10] At the first international conference on negative emissions, held in May 2018 in Gothenburg, Sweden, Sweden's state secretary for climate change discussed an official inquiry into carbon removal in Sweden—but via forests, soil, and bioenergy. In the UK, the Royal Society and the Royal Academy of Engineering released a major report on greenhouse gas removal in September 2018 recommending, among other things, the immediate implementation of "a global suite of [carbon removal] methods to meet the goals of the Paris Agreement."[11] Meanwhile, fossil fuel companies have been relatively silent on the topic of carbon removal, though a 2016 report from Shell sketches out a potential role for carbon removal in dealing with hard-to-decarbonize sectors.[12] In their "Sky" scenario, Shell also points out that countries successful in negative emissions could transfer them to countries that are laggards in mitigation.[13]

Carbon removal has downsides that need to be explored

Although various carbon removal methods may play a critical role in the overall response to climate change, they do have downsides, both individually and collectively. The downsides of different approaches to carbon removal vary from one method to the next, but these method-specific downsides share two commonalities: they are scale-dependent, meaning that the downsides get worse as the particular method is scaled up to capture more carbon; and they are context-dependent, meaning that the downsides depend on environmental, technological, and social circumstances. For an overview of the downsides associated with each method, see the method-specific fact sheets available on our web site or one of the reviews available in the academic literature.[14]

To appreciate the importance of scale- and context-dependence, consider the example of bioenergy with carbon capture and storage (BECCS). The world might be able to remove up to a few billion tons of CO_2 per year through BECCS that relies entirely on agricultural waste, forest residues, and similar inputs, which could have minimal impact on land use if accompanied by careful policy. Removing, say, 10 billion tons per year, however, would require devoting roughly 380–700 million hectares of arable land—an area up to twice the size of India—to growing bioenergy crops,[15] which would negatively affect food security, land security, water conservation, and biodiversity. Turning to examples of context-dependent effects, the climate and air-quality impacts of

What Is a Carbon Budget?

Because much of the CO_2 that humanity emits will remain in the atmosphere for hundreds or thousands of years, the amount of warming humanity causes will depend largely on the cumulative amount of CO_2 we emit. This makes it possible to calculate the total amount of CO_2 humanity can still emit without exceeding any particular temperature target. That amount of CO_2 is often called a carbon budget.*

In its Fifth Assessment Report, the IPCC concluded that if humanity can limit its cumulative emissions between 2011 and 2100 to about 1,000 billion metric tons of CO_2 ($GtCO_2$), total warming would likely stay below 2°C.† Humanity is burning through that budget rapidly, having emitted more than 200 $GtCO_2$ since 2011. The IPCC's new Special Report on 1.5°C concludes that the carbon budget may be in fact larger than indicated in the Fifth Assessment Report; this is expected to be a matter of continued scientific debate. However, scientists are quick to point out that newer recalculations do not change the urgent need for emissions reductions.

Carbon removal could expand this carbon budget. For example, if humanity removed 500 $GtCO_2$ from the atmosphere over the rest of this century, we could likely limit warming to 2°C even if we collectively emitted another 1,300 $GtCO_2$.

* Note that this report expresses emissions and carbon budgets in terms of tons of CO_2, whereas some other publications express measurements in terms of tons of carbon. Because CO_2 weighs 3.67 times as much as carbon, readers should take care when comparing estimates from different sources.

† This estimate, which accounts for the effects of both CO_2 and non-CO_2 greenhouse gases, comes from the Summary for Policymakers from Working Group I of the IPCC. For an overview of the climate implications of less stringent carbon budgets, see the Summary for Policymakers from WorkingGroup III.

growing, processing, and transporting biomass for BECCS would be different in a context dominated by electric vehicles and railroads than one dominated by fossil-fueled tractors and trucks. Finally, the social impacts of diverting land from food crops to fuel crops will depend on global food demand, which in turn depends on population growth and demand for meat. Similar points about scale- and context-dependence apply to all other methods of carbon removal. This makes it important to evaluate the downsides of any particular method at different levels and across different scenarios.

Taking all of the different methods collectively, carbon removal raises three main problems. The first is popularly known as the "moral hazard" problem, which is that policymakers and publics might use the prospect of large-scale carbon removal as an excuse to avoid cutting greenhouse gas emissions or to delay adapting to likely impacts. The limited empirical research so far has turned up mixed results, with knowledge of carbon removal decreasing support for emissions reductions among some groups but not others.[16] The risk looms large in many commentators' minds, however, and the problem may intensify as more and different voices enter the conversation, which has so far been restricted largely to academics and climate policy experts.

The second problem is the potential burden on future people: building near-term climate policies on the assumption that carbon removal will be able to remove billions of tons of CO_2 later in the century amounts to a "high-stakes gamble" with the planet's future.[17] If societies emit more CO_2 now with the expectation of cleaning it up later, but carbon removal methods fail to deliver because of social, economic, or environmental limitations, future generations will be burdened with much more climate change than they would have faced if current generations had cut emissions more quickly.

The third problem, which might be called a "readaptation" problem, would arise in an overshoot scenario in which temperatures peak above the desired target and gradually fall again as CO_2 levels drop: societies and ecosystems that had adapted to the higher temperatures would have to change again as temperatures decline.[18]

Given these downsides, the conversation about carbon removal cannot just be about how to scale it up to capture billions of tons of CO_2. These discussions must also address which forms of carbon removal to use; where, when, and how much to use them; and the policies and institutions needed to foster responsible carbon removal. Therefore, a crucial, early piece of that conversation involves setting out a research agenda for evaluating different methods of carbon removal, both individually and as a portfolio.

In summary, there are two main reasons to open up a more expansive conversation about carbon removal: (1) the weight of scientific analysis suggests that carbon removal at large scales will likely be necessary to combat climate change; and (2) there are lots of ways that development of carbon removal technologies or practices could be done poorly or have negative side-effects. A clear-eyed, critical conversation about carbon removal options is urgently needed.

2. A Portfolio of Options

Scientists have identified a wide range of options for removing carbon from the atmosphere. These approaches differ in many ways—not only in terms of how much carbon they can remove and at what cost, but also the kinds of risks and co-benefits they carry, as well as in the mechanisms by which they capture carbon and the forms in which they store it. This makes it difficult to assess carbon removal in the abstract: different carbon removal technologies and practices have different profiles. But, it is also difficult to assess each method of carbon removal in isolation, since different methods can complement or compete with one another in various ways. The best way to assess carbon removal, therefore, is as a portfolio of options that might be mixed-and-matched and combined with emissions reductions measures and adaptation efforts to devise the best overall climate policy possible.

This raises two key points:

1. Carbon removal cannot be meaningfully considered apart from the rest of the climate policy portfolio. It only makes sense to look at carbon removal options alongside traditional mitigation and adaptation options, since in some cases carbon removal may complement such approaches and in other cases may compete with them.
2. There is no silver-bullet carbon removal option. Based on current understandings, there is no single carbon removal option that could plausibly be developed at sufficient scale to safely remove hundreds of billions of tons of CO_2 from the atmosphere this century. It makes most sense, then, to look at carbon removal as a portfolio of potential options, rather than as a set of discrete, stand-alone options.

There are various ways to categorize different methods of carbon removal. Figure 2 categorizes them according to where they would be implemented—for instance, on agricultural land or in coastal waters. Doing so highlights the fact that some methods would compete with or complement each other because they would occupy the same physical space. The best-known example is that afforestation/reforestation competes with most forms of BECCS because land devoted to forests cannot be used for bioenergy crops.

The interactions between different methods of carbon removal brings out another reason to assess carbon removal in terms of a portfolio of methods: the maximum rate of carbon removal from a portfolio of methods may be less than the sum of the maximum rate of each method in the portfolio. In other words, we cannot determine how much carbon a portfolio of methods can remove just by adding up the maximum potential of each method in the portfolio. For instance, while it might be feasible to remove 3.5 $GtCO_2$ per year through afforestation or 5 $GtCO_2$ per year through BECCS by 2050, it would be more difficult to remove 8.5 $GtCO_2$ per year with afforestation *and* BECCS because of competition for land.

This section provides a brief introduction to eight prominent carbon removal methods that might feature in such a portfolio: afforestation/reforestation (AF/RF), bioenergy with CCS (BECCS), biochar, coastal "blue carbon," direct air capture and carbon storage (DACCS), enhanced mineralization (or enhanced weathering), ocean alkalinization, and soil carbon sequestration. This list is not exhaustive, but it does cover the most frequently discussed options. For overviews of the various co-benefits and negative side effects of these methods, see Table 1 or the method-specific fact sheets on our web site. More detailed overviews of potentials, costs, co-benefits, and negative side effects are available in the academic literature.[19]

- **Afforestation/reforestation (AF/RF)** involves planting or replanting forests over large areas. These new forests would absorb carbon in both the trees and the soil as they grow, with the rates and side effects depending on the mix of trees being planted. Forests would sequester the captured carbon for as long as they remain standing, which means that, as with other biological methods of carbon removal, the climate benefits of AF/RF are reversible. AF/RF projects are already underway and are well-integrated into existing policies and institutions.
- **Bioenergy with carbon capture and storage (BECCS**) involves growing or collecting biomass, processing it, converting it to biofuels or energy, capturing the resulting carbon, and storing it underground or in long-lasting products. There are many different ways to implement BECCS, depending on whether the biomass is purpose-grown or collected from agricultural wastes, forest residues, or other sources; whether it is converting to liquid or gaseous fuels or pelletized and burned to generate heat or electricity; whether it is sequestered in depleted oil fields, saline aquifers, basalt formations, or long-lasting products; and so on, all with major implications for BECCS' climate impact and overall sustainability.[20] In addition to various pilot projects, there is currently one, small-scale commercial BECCS plant using dedicated saline reservoir storage in operation, in Decatur, Illinois.[21]
- **Biochar** is a kind of charcoal produced by heating biomass in a low-oxygen environment. When buried or ploughed into soils, it locks carbon away for decades or centuries while enhancing soil quality. It can therefore complement most other land-based forms of carbon removal, although it would compete with BECCS for biomass inputs. As with BECCS, the amount of carbon ultimately removed with biochar depends on what kind of biomass is used, how it is sourced and heated, whether the soils are eventually disturbed, and other details of the process. Biochar is currently produced on a small scale, but large-scale field trials are needed to refine estimates of its potential and side effects.
- **Coastal "blue carbon"** refers to carbon sequestered by restoration and better management of coastal wetlands and seagrass meadows. These areas currently hold large amounts of carbon in biomass and sediments. Restoring degraded wetlands or seagrass meadows or creating new ones could increase the total amount of carbon dioxide they absorb from the atmosphere while also providing important co-benefits. Some researchers have also proposed growing macroalgae and sequestering the captured carbon in various ways. Estimates of the global potential for carbon removal with blue carbon are not yet available.
- **Direct air capture and carbon storage (DACCS)** refers to processes that capture CO_2 with purpose-built machines and store the CO_2 in the same kinds of geological reservoirs or long-lasting products used for BECCS. These machines capture CO_2 from ambient air using various chemical processes and then separate the CO_2 for sequestration. Whereas natural materials, such as biomass

or rocks, provide the primary inputs to other carbon removal technologies, the primary input in DACCS is energy. Direct air capture technology is still in the early stages of development, with one commercial plant in operation in Switzerland and a demonstration plant running in Canada. Neither is currently sequestering the captured CO_2: the Swiss plant, operated by Climeworks, pumps it into a greenhouse to fertilize plants, and the Canadian plant, operated by Carbon Engineering, uses it to produce synthetic fuels.

- **Enhanced mineralization** involves accelerating the natural processes by which various minerals absorb CO_2 from the atmosphere. The process begins by mining specific kinds of rock, such as olivine or basalt. One prominent proposal for implementation would involve grinding those rocks into powder and spreading the powder over soils, where it would react with the air to form carbonate minerals. Minerals released in the process could enhance soil quality.[22] Other options include exposing powdered rock to CO_2-rich fluids or spreading it over the ocean. Enhanced mineralization remains at the very early stages of research and development, but the long-term potential may be quite large.

- **Ocean alkalinization** involves spreading alkaline substances, such as lime, over the ocean, where it would absorb CO_2. This is often classified as a type of enhanced mineralization, but it offers the added benefit of directly counteracting ocean acidification by increasing the pH of seawater. Like enhanced mineralization in general, research on ocean alkalinization is still in very early stages.

- **Soil carbon sequestration** refers to a number of different practices for increasing the amount of carbon stored in soils, especially agricultural soils. Prominent examples include no-till agriculture, manuring, and cover crop rotation. Because they improve soil quality, these practices can contribute to improved crop yields. Soil carbon sequestration methods are already in use and ready to scale up, but key challenges remain, including encouraging widespread adoption and ensuring long-term maintenance of the practices to keep the carbon in the ground.

There are also various proposed methods of marine carbon removal that are not explored in this report.[23] Of these, the best known is ocean fertilization, which attracted considerable interest in the 2000s but now receives less attention,[24] primarily because of concerns about limited effectiveness and potential impacts on marine ecosystems.

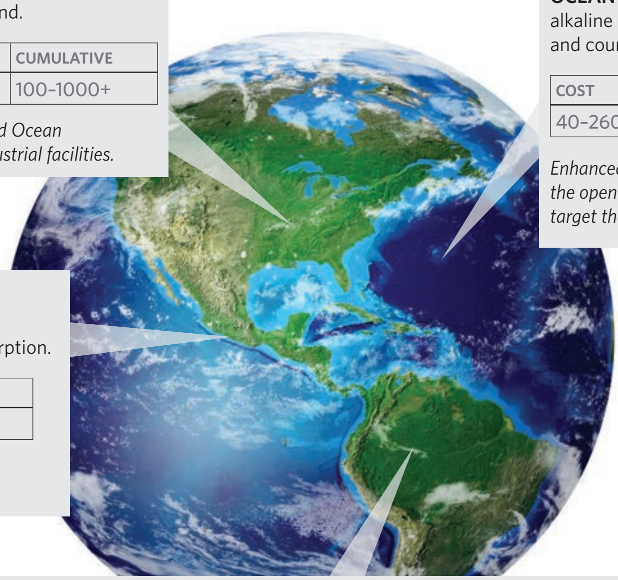
The differences between these methods reveal a further reason to think in terms of a portfolio of methods: the relevance of timing and sequencing. Afforestation, blue carbon, and soil carbon sequestration are ready for widespread adoption or deployment. Furthermore, these relatively low-cost options provide important near-term co-benefits, such as protecting biodiversity, providing ecosystem services, and promoting food security, respectively. Biochar arguably fits this description, as well. These near-term options, however, face two problems: they are saturable, meaning that there is an upper limit to the amount of carbon that could be sequestered via each method; and none of them achieve permanent sequestration, since captured emissions could be released through degradation of forests, wetlands, and soils. The other options—BECCS, DACCS, enhanced mineralization, and ocean alkalinization—may be able to permanently sequester extremely large amounts of CO_2, but they are generally more expensive, will take longer to scale up, and depend more heavily on abundant low-carbon energy sources. In preparing long-term climate strategies, then, organizations might do well to think about how a portfolio of approaches to carbon removal would change over time to combine short-term opportunities with more permanent long-term approaches.

Figure 2: **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 ($/tCO_2$)
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

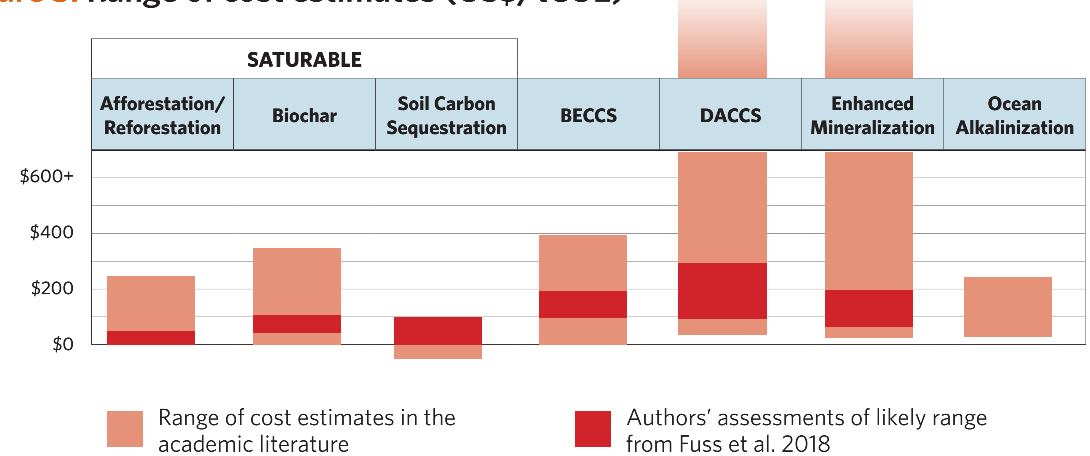
Estimates come from Fuss et al. 2018, "Negative Emissions—Part 2: Costs, Potentials, and Side Effects," *Environmental Research Letters* 2018. https://doi.org/10.1088/1748-9326/aabf9f. Estimates of cost and potential rate of carbon removal reflect the experts' assessments in Fuss et al. 2018 based on their review of existing studies, except for the cost of ocean alkalinization, which reflects the full range in the literature. See http://www.co2removal.org.

Table 1: Potential and side effects of carbon removal methods

	SATURABLE						
	Afforestation/ Reforestation	Biochar	Soil Carbon Sequestration	BECCS	DACCS	Enhanced Mineralization	Ocean Alkalinization
Potential sequestration rate by 2050 ($GtCO_2$/yr)	0.5-3.6	0.5-2	2-5	0.5-5	0.5-5	2-4	N/A
Potential rate by 2100 ($GtCO_2$/yr)	0.5-7	1-35	0.5-11	1-20+	1-20+	0-20+	1-27
Cumulative potential by 2100 ($GtCO_2$)	80-260	78-477	104-130	100-1170	100-1000+	100-367	N/A
SIDE EFFECTS (SCALE-DEPENDENT)							
Air Pollution	⊖	⊖	⊖	⚠	?	⚠	?
Albedo	⚠	⊖	⊖	⊖	?	⊖	?
Biodiversity	⚠	⊖	⊖	⚠	?	⊖	?
Ecosystem Changes	⊖	⊖	⊖	⊖	?	⊖	?
Food Security	⚠	⚠	👍	⚠	?	⊖	?
Ground/Water Pollution	⊖	⊖	⊖	⊖	?	⚠	?
Soil Quality	👍	👍	👍	⊖	?	👍	?
Mining & Extraction	⊖	⊖	⊖	⊖	?	⚠	⚠
Trace GHGs	⊖	👍	⚠	⚠	?	⊖	?

👍 Desirable change ⚠ Undesirable change ⊖ No significant change ? No estimate available

Figure 3: Range of cost estimates (US$/$tCO_2$)



Estimates of potential, costs and side effects come from Fuss et al. 2018, "Negative Emissions—Part 2: Costs, Potentials and Side Effects," *Environ Res Lett* 2018, https://doi.org/10.1088/1748-9326/aabf9f and J. Minx et al., "Negative Emissions—Part 1: Research Landscape, Ethics and Synthesis," *Environ Res Lett* 2018, https://doi.org/10.1088/1748-9326/aabf9b, and the underlying data for those papers, which is available from http://www.co2removal.org. Relevant estimates for blue carbon are not available.

3. Mapping the Landscape of Carbon Removal

Policy: A Growing but Fragmented Area

Governments at every level can do much to guide the evolution of carbon removal. Clear-cut roles for national governments include (1) *supporting research* and development of technologies and practices, (2) *regulating* safe and reliable disposal of carbon dioxide, (3) *incentivizing* certain carbon removal methods, as part of broader climate policy, via policy and programming using both carrots and sticks, (4) *building and maintaining infrastructure* related to carbon removal, (5) *planning* land use and land management in ways that balance carbon removal alongside other goals, (6) *informing* stakeholders about carbon removal technologies and practices, and (7) *negotiating* with other countries to form carbon removal policy in the international arena. There are also less clear-cut or novel roles for governments to play, such as developing or employing carbon removal certification schemes which meet environmental justice guidelines and social safeguards. Regional, local, and international agencies and governments also have roles in these seven functions, to varying degrees.

In practice, the current policy conversation is fragmented. Although individual methods have been the subject of policy and government research, most levels of government have not addressed carbon removal comprehensively. It is too early to say whether actors will reach consensus on the role of carbon removal or on the best methods for pursuing it. In the meantime, there are some noteworthy developments at the national, subnational, and international level.

United States

At the US federal level, an ongoing National Academies study, "Developing a Research Agenda for Carbon Dioxide Removal and Reliable Sequestration," is preparing recommendations for further research. Federal agencies have a patchwork of programs relating to carbon removal. The Department of Energy has an Industrial Carbon Capture and Storage Program and has funded work related to BECCS and DACCS. ARPA-E is a venue for more exploratory research, and their MARINER program has looked at some carbon removal work. The US Department of Agriculture's Natural Resource Conservation Service (NRCS) has designed modeling tools widely used for soil carbon sequestration. The Department of the Interior and the National Science Foundation have also funded projects. Daniel Sanchez and colleagues recently published a review of projects and opportunities at the federal level. They calculate that $310 million has cumulatively been allocated for carbon removal research, development, and deployment, three quarters of which funded CCS demonstration at biorefineries. They discuss legislative opportunities for supporting carbon removal, such as the farm bill or the energy bill.[25] Soon after Sanchez and colleagues conducted their review, Congress expanded a tax credit, generally known as the 45Q tax credit, that incentivizes carbon sequestration. This tax credit has provoked controversy because it also incentivizes a type of carbon sequestration called enhanced oil recovery, which involves injecting captured CO_2 into depleted oil and gas reservoirs to boost production. Supporters of this provision in the 45Q tax credit say it provides a valuable niche market to encourage development of carbon removal technologies, while critics say it undermines the climate benefit of carbon sequestration.

There are also opportunities for engaging with carbon removal at state and provincial levels. Alberta and California are two jurisdictions that have made progress with incentivizing soil carbon storage. A Governors' Partnership between governors of six states (Kansas, Louisiana, Montana, Oklahoma, Utah, and Wyoming) is promoting carbon capture, and the Regional Carbon Capture Deployment Initiative is looking at the prospects of carbon capture in the Midwest.

Other Domestic and Regional Contexts

In other nations, there are also currents of interest, albeit not yet at a scale that would make a difference in the climate. The UK and Germany have provided relatively minor amounts of dedicated funding for carbon removal research, on the order of tens of millions. In general, there is an implicit tension between the role of government to regulate versus incentivize carbon removal. The approach does not yet seem to be decided. And because previous attempts towards promoting bioenergy and CCS have failed or faced scrutiny (particularly in Europe), it is not obvious that it will be politically easy to incentivize carbon removal technologies and practices.

When it comes to politics in the European Union, Oliver Geden and colleagues outline three potential scenarios: (1) that the EU could emerge as a key policy developer, and integrate carbon removal into the European Commission's climate policy strategy and provide research funding; (2) that carbon removal would be driven through actions by individual member states, aiming to compensate for residual emissions in their industries; (3) that carbon removal could be driven by the private sector, with small-scale projects towards corporate social responsibility.[26] All of these could pave the way for eventual carbon stock maintenance policies. Geden and colleagues caution, though, that even if all these emerged in parallel, the EU would still not be on a trajectory of carbon removal envisioned in modeling scenarios.

International

Some analysts have argued that without international coordination, nations are unlikely to develop carbon removal policies and technologies on their own.[27] Internationally, work on natural climate solutions takes place under many UN and international research organizations. Forest carbon is addressed via REDD+ at the UNFCCC, soil carbon is addressed by the UN Food and Agriculture Organization as well as initiatives like "4 per 1000", and the International Blue Carbon Initiative is a collaboration initiated by UN Environment and including several UN and international NGOs. When it comes to CCS, the International Energy Agency researches and tracks the issue, and they have recently been exploring BECCS. Again, however, these discussions fall well short of including carbon removal more broadly in international fora like the UNFCCC and REDD+.

Academic Landscape: An Idea Incubator

There is a large and rapidly growing body of academic work on carbon removal, especially but not exclusively in the natural sciences. A team based at the Mercator Research Institute on Global Commons and Climate Change recently published a systematic review of the academic literature, which provides an excellent and accessible overview of the field.[28]

Although there are many individual researchers working on various aspects of carbon removal, there are few academic research centers dedicated exclusively to carbon removal. For example, the University of Michigan's Global CO_2 Initiative is focused on technology development and commercialization; Arizona State University also has a Center for Negative Carbon Emissions. Social science research in this area—in terms of looking at carbon removal in general—is sparse, though CCS has been the subject of many studies. In general, many people are unfamiliar with carbon removal, which means that methods like surveys are less helpful, and methods like deliberative workshops are more appropriate. Currently, a significant share of the social science research on carbon removal is taking place in the UK, where projects are funded through the federal government's Greenhouse Gas Removal program; these include deliberative and scenario-building workshops with stakeholders and citizens about different technologies, as well as research into the question of mitigation deterrence. No such social science research has been widely funded in the United States. However, there are a few university-led initiatives underway which highlight interdisciplinary approaches. One is the New Carbon Economy Consortium, involving Arizona State University, Purdue, Iowa State, and Lawrence Livermore Labs along with Carbon180 (formerly known as the Center for Carbon Removal). Other environmental institutes, such as Cornell's Atkinson Center for a Sustainable Future, are planning interdisciplinary work about the topic. In short, research has been largely focused on engineering and technology development, but as the topic becomes more prominent, opportunities for interdisciplinary studies are poised to grow.

Philanthropy: A Blip on a Crowded Radar

Philanthropic foundations play a growing strategic role in addressing climate change. A recent analysis found that much climate philanthropy goes to renewable energy, energy efficiency, and communication; just 2 percent went to promoting other low-carbon sources or innovation.[29] However, some organizations, like the Hewlett Foundation, invest in carbon removal and advanced zero-emission technologies, which they note "will require both risk tolerance and a willingness to embrace outcomes over a longer-than-usual time scale"; ClimateWorks is also exploring carbon removal strategies.

An overview of carbon removal-related philanthropy is found in a report by the Center for Carbon Removal, which analyzed a database of grantmaking from 2008–2014, and found that philanthropies averaged about $0.8 million per year donated to carbon removal projects, or 0.3 percent of total climate-related philanthropy in that period.[30] They argue that the opportunity is great, because philanthropies are free from the need to deliver high financial returns as well as from electoral pressures. However, they explain that philanthropists they interviewed suggested that these projects are high cost, complex, and uncertain compared to mitigation projects they might fund; instead, carbon removal projects were funded largely for co-benefits, and grants to biological carbon removal projects were often done under programs of agriculture or economic development, not climate change. Moreover, CCS work was motivated as being an abatement strategy for fossil fuel emissions rather than as part of a carbon removal strategy. The report argues, however, that philanthropies have the ability to elevate the conversation on carbon removal, articulate the case for research, development, and deployment, and advocate for appropriate policy mechanisms.

Corporate Action: A Glimmer of Interest

The private sector landscape of carbon removal is marked by separate streams of work that are not directly in conversation with one another. The first stream aims to shape the policy landscape. There are large industry coalitions dedicated to promoting CCS. The Global CCS Institute includes Shell, BHP, China Steel Corporation, Toshiba, and other large companies, as well as governments from the UK, US, Australia, China, and Japan. The Carbon Capture Coalition, a non-partisan coalition that recently rebranded from the National Enhanced Oil Recovery Initiative, brings together industry as well as labor unions and NGOs, with a diverse list of members including Arch Coal, Shell, Peabody Energy, the AFL-CIO, the International Brotherhood of Electrical Workers, the National Audubon Society, and The Nature Conservancy, among others. In addition to these large coalitions, there are smaller companies like Nori seeking to facilitate carbon removal and shape accreditation through technologies like blockchain.

A separate stream in the corporate landscape is a set of early movers on technology development. In Silicon Valley, "carbontech" is becoming a buzzword. Startup accelerator Y Combinator, for example, issued a call for carbon removal startups. More significantly, though, there are a limited number of companies operationalizing technological forms of carbon removal. Climeworks in Switzerland and Carbon Engineering in Canada are two companies with operational direct air capture facilities, though neither one is currently sequestering the captured carbon. Archer Daniels Midland operates a BECCS plant in the United States. "Carbon-to-value" efforts that aim to create profitable, long-lived products from captured carbon are also beginning to attract interest.

A final stream focuses on rethinking established work on land-based carbon removal. Companies like Annie's, Ben & Jerry's, and Danone signed on to a definition of regenerative agriculture, and the Regenerative Organic Alliance, led by Patagonia, the Rodale Institute, and Dr. Bronner's, has organized a Regenerative Organic Certification. Many companies, especially in the transportation sector, participate in afforestation carbon offset programs.

Civil Society: A Diversifying Conversation

In one sense, many of the issues related to carbon removal are familiar to NGOs working on climate-related issues: conceptualizing and accounting for carbon sinks, measuring blue carbon, formulating positions on CCS with and without enhanced oil recovery, etc. In another sense, the new awareness of and mandate for carbon removal makes this somewhat of a new playing field, with some new actors, and a sense that the issue could move quite quickly.

The conversation about whether and how carbon removal can or ought to be a part of responding to climate change has been slow to get off the ground in the civil society arena. The loudest voices so far have either strongly opposed or strongly supported carbon removal—either in general or in specific forms. It remains to be seen how most NGOs will approach the issue. It is clear, though, that environmental and human rights NGOs will need to play a guiding role in the thorough and informed societal assessment of the potential role of carbon removal in a strategic climate policy.

There is an emerging spectrum of perspectives on carbon removal. On one end stand groups who see carbon removal as necessary in addressing climate change and take a broadly optimistic outlook about the potential of one or more methods for carbon removal. Leading examples include the Breakthrough Institute and Carbon180. On the other end of the spectrum stand several groups opposed to the consideration of carbon removal as a legitimate response to climate change. These groups argue that carbon removal is yet another "false solution" or "techno-fix" akin to solar geoengineering, either because the optimistic forecasts for carbon removal technologies are unlikely to bear out or because large-scale technological schemes are a big part of the reason that the world now faces global environmental disruption. These groups also tend to believe that the human rights impacts (such as land grabs for BECCs) and environmental consequences (such as disruptions to marine life from ocean iron fertilization) are likely to be unmanageable and to outweigh the benefits to vulnerable groups. This group of carbon removal skeptics includes The ETC Group, Biofuel Watch, and the Heinrich Boell Foundation.

There is, in addition, a growing middle in this conversation. Most NGOs have only just begun serious assessment of carbon removal as a package of responses to climate change (although many have long paid attention to land-based responses such as afforestation). This is a pivotal time in defining the politics of carbon removal, a process that will be shaped by the entrance of civil society into the debate.

4. Carbon Removal and Mitigation

One key question affecting uptake of carbon removal in policy and civil society circles is whether it is categorized as a kind of mitigation. This is not just an academic or terminological dispute. How various actors categorize carbon removal has important social, political, and policy implications and affects whether and how those actors discuss carbon removal. It affects where various government agencies, NGOs, and research funders direct their attention and funds. It affects policy priorities and choices. It potentially determines whether or in what forms carbon removal finds its way into countries' Nationally Determined Contributions under the Paris Agreement. By analogy, consider the implications of counting bioenergy as a form of renewable energy in renewable portfolio standards. How we categorize things matters.

So where does carbon removal fit in the broader portfolio of climate responses? Is it a form of mitigation? Is it a form of climate engineering? Is it in a category of its own? Do different methods of carbon removal belong in different categories? There is currently no consensus on this debate. Those who are wary of carbon removal for one reason or another tend to resist counting it as mitigation, especially in its more "technological" forms, such as DACCS. Some advocates of carbon removal have resisted the tendency to classify it as climate engineering so as to distance it from the controversies surrounding solar geoengineering—a proposed climate response that would involve reflecting a small fraction of incoming sunlight back into space to cool the planet. Some commentators put carbon removal in its own category, distinct from both traditional mitigation options and from climate engineering.

In the broadest sense, there are three possible options for categorizing carbon removal in relation to mitigation.

Option 1: Carbon removal is not mitigation

The first option is to insist that there is *no* form of carbon removal that counts as mitigation. This option faces an immediate difficulty: the term *mitigation* is typically understood and used in ways that count certain methods of carbon removal, like afforestation, reforestation, and soil carbon sequestration, as a form of mitigation. To take one important example of this usage, the UNFCCC process has counted these activities as mitigation from the beginning. The Convention itself explicitly counts the enhancement of sinks as a form of mitigation, the Kyoto Protocol counts enhancement of sinks toward emissions reductions targets, and the Paris Agreement encourages Parties to enhance their "greenhouse gas sinks."

Option 2: Only natural forms of carbon removal are mitigation

The second option is to count only *some* forms of carbon removal as mitigation. There are many ways to do this, but perhaps the most salient at the moment is to divide methods of carbon removal into "natural" and "technological" approaches, counting only the former as mitigation. This fits with the existing practice of counting afforestation, reforestation, and soil carbon sequestration as mitigation while excluding more technological approaches like direct air capture. It also fits with many people's intuitive classification of various forms of carbon removal. Strictly speaking, it contradicts the UNFCCC's definition, according to which a sink is "any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere,"[31] though there are legal subtleties here and, regardless, one might argue that the UNFCCC's definition predates a clear understanding of the full range of carbon removal technologies and practices and should be revised to exclude certain methods. Another way to think of this option is as the suggestion that "carbon removal" is an unhelpful concept because it fails to divide the options into the appropriate categories.

Option 3: All forms of carbon removal are mitigation

The third option is to count all forms of carbon removal as mitigation. While the conceptual motivation for this is clear—mitigation encompasses emissions abatement and sink enhancement, and carbon removal technologies and practices enhance or create natural or artificial carbon sinks—such a move may raise red flags in the climate policy community. Rhetorically, categorizing *all* forms of carbon removal as mitigation might suggest that we can simply *replace* emissions abatement with carbon removal, which is very clearly a mistake. It may also signal a general acceptance of all forms of carbon removal, whereas many people are uncomfortable with at least some methods of carbon removal. On the other hand, the existing practice of counting "natural" sink enhancement as a form of mitigation has not obscured the need for emissions abatement, and prioritizing emissions abatement in general has not prevented anyone from opposing specific forms of low-carbon energy, such as nuclear power, large hydroelectric dams, or fossil fueled power plants with CCS. The relevant distinction, on this approach, is not between mitigation and carbon removal, but between emissions abatement and carbon removal—and within each of those categories, between unacceptable and acceptable approaches.

Our View: Carbon Removal is Mitigation; Emissions Abatement Takes Priority

In light of these considerations, our position is that while all forms of carbon removal count as mitigation, not all forms of mitigation are equally good. Most importantly, emissions abatement must take precedence because carbon removal is too slow, expensive, or limited to compensate for anything close to the current level of global emissions. Some methods of carbon removal are also reversible, meaning that captured carbon could be released into the atmosphere again. Furthermore, we emphasize the importance of continuing to distinguish emissions abatement from carbon removal; to collapse that distinction would obscure important differences between preventing greenhouse gas emissions in the first place and trying to capture greenhouse gases after the fact. Carbon removal ought to be seen as a supplement to efforts to decarbonize the global energy, transportation, industrial, and food sectors, which must remain the highest priority of global climate policy. Furthermore, categorizing all methods of carbon removal as mitigation is not an endorsement of all methods, either individually or collectively: some methods will likely prove too risky or costly to be acceptable and all methods will face limitations in terms of when, where, at what scale, and under what conditions they could be appropriately deployed.

5. Scoping the Assessment Agenda

Many of the existing assessments of carbon removal have focused on various methods' technical potential and the limitations or challenges created by their environmental or social impacts. These early assessments have generally considered various methods in isolation, even though it seems likely that societies would—either individually or collectively—adopt a portfolio of methods to remove carbon at climate-relevant scales. Thus, existing assessments remain incomplete.

Based on the discussions in the preceding sections, a complete assessment of carbon removal's role in national and international mitigation portfolios rests on three premises:

1. Societies should regard carbon removal as, at best, a supplement to cutting emissions; it would be a mistake to rely on carbon removal *instead* of reducing greenhouse gas emissions.
2. All forms of carbon removal count as mitigation, but this does not settle the question about which methods are acceptable parts of a national or international mitigation portfolio.
3. Assessing any individual method of carbon removal requires thinking about whether, how, and under what conditions that particular method can be used sustainably and effectively.

This last premise highlights the complexity of assessing any particular method of carbon removal. Assessing each method faces several difficulties:

- *There are many ways of implementing each method.* For instance, energy companies could source different kinds of biomass from different parts of the world, enhanced mineralization could rely on different minerals processed in different ways, and biochar manufacturers could burn either fossil fuels or hydrogen to convert wood to charcoal.
- *The impacts of different ways of implementing each method will differ from place to place and under different environmental and socioeconomic conditions*. For instance, enhanced mineralization would work more quickly in the tropics than at higher latitudes, soil carbon sequestration would only be permanent if temperatures stay low enough, ocean alkalinization would provide greater benefits in scenarios with more severe ocean acidification, and afforestation would face less competition for land if the global population and demand for meat grew more slowly.
- *Some methods can compete with or complement one another*. BECCS would compete with afforestation for land, whereas soil carbon sequestration and enhanced mineralization might reinforce one another by enhancing soils in complementary ways.

Thus, a full assessment of carbon removal requires looking not just at individual technologies and practices but at different possible portfolios of methods, just as a full assessment of individual renewables requires looking at different possible portfolios of energy sources. It may well turn out that some methods prove to be unsustainable in all plausible circumstances while others turn out to be sustainable and effective in a wide range of plausible scenarios. This may affect if, when, and how societies adopt different methods.

Addressing all of these issues requires answering a wide range of questions about each method under assessment. Table 2 (on p. 22) identifies key questions that a complete assessment would need to answer, along with an example of each question as it applies to a particular method. Existing research has answered some of these questions for some ways of implementing some methods, but much more remains to be done.

As Table 2 demonstrates, a complete assessment of carbon removal requires a broad effort combining the expertise of physical scientists and technical experts with that of scholars and NGOs specializing in environmental concerns, social issues, and public policy. Fitting carbon removal into the post-Paris framework of bottom-up climate action also requires the expertise of governments and nationally- or regionally-focused NGOs that can tailor these assessments to particular places. Addressing the long-term questions will require the expertise of scenario modelers and could benefit from the discipline imposed by recent efforts to develop Shared Socioeconomic Pathways for climate modeling and climate policy assessment.

Looking specifically at the role that civil society can play in the broader debate about carbon removal, there are also a number of near-term strategic questions that cut across multiple methods:

- *How can civil society guard against the risk of a "moral hazard" problem?* Although empirical evidence is scarce, many commentators fear that the prospect of carbon removal will slow efforts to cut emissions.
- *Should NGOs support incentives for and responsible innovation in carbon removal or in particular methods—or should they adopt a cautionary stance toward some methods?* Most methods of carbon removal would take decades to reach climate-relevant scales, and near-term policies and campaigns could influence the rate of research, development, adoption, and upscaling.
- *Should NGOs push for a particular way of including, excluding, or governing various methods of carbon removal in the international climate regime?* As the example of afforestation and REDD+ shows, it can be time-consuming and difficult to craft international climate policy around a particular method.
- *How could NGOs support good regulation, certification, and monitoring for various methods of carbon removal?* For NGOs that do want to support—or at least shape the governance of—some methods, what role can they play in promoting appropriate regulation, certification and monitoring processes? Examples include verifying or certifying soil carbon sequestration and monitoring injection wells for geological carbon sequestration.
- *What role should niche markets play in the development of different methods of carbon removal?* BECCS and DACCS produce pure streams of CO_2, which can be used for enhanced oil recovery and synthetic fuels ("air-to-fuels"). On the one hand, these particular niche markets provide important financial support to fledgling carbon removal technologies, but they also support existing fossil fuel infrastructures. What stance should NGOs take on the use of and policy support for these niche markets?

Table 2: Questions for assessing carbon removal

	ASSESSMENT QUESTION	EXAMPLE
EFFECTIVENESS	Under what circumstances would this method be **cost effective**?	At what carbon price or subsidy level would DACCS be feasible within a given country or region?
	How much carbon could this method sequester annually and cumulatively, globally or in a particular place?	How much carbon could afforestation capture in Nigeria, both annually and cumulatively?
	How much "carbon debt" would this method incur if implemented in a particular way in a particular place, and how long would it take to pay off that debt and achieve **net negative lifecycle emissions**?	How much carbon would be emitted into the atmosphere by converting pasture to farmland for BECCS, and how long would it take for the that plot of land to generate net-negative lifecycle emissions?
	Under what conditions would carbon sequestered by this method be **released back into the atmosphere**?	What would happen to "blue carbon" reservoirs if sea levels rise by half a meter?
IMPACTS	What are the **environmental impacts** of this method at various scales and using different methods?	What are the impacts on biodiversity, soil and atmospheric quality and health, water systems, and the like, of removing 100 million tons of CO_2 per year via BECCS that captures CO_2 during corn ethanol fermentation?
	What are the **social impacts** of this method at various scales and using different methods?	How would removing 500 million tons of CO_2 per year via enhanced mineralization affect jobs in American mining communities?
	Which method(s) of implementing a particular method have the **best combination of positive and negative side effects** in particular circumstances?	What would be the best way(s) to achieve widespread application of biochar in Madhya Pradesh, India?
	How would this method affect **social and environmental justice** at different scales, in different places, and using different methods?	How would widespread adoption of soil carbon sequestration among Colombian farmers affect social justice in Colombia?
CIRCUMSTANCES	What social or policy changes would be needed for widespread **adoption and upscaling** of this method to be plausible?	What agricultural extension efforts would be needed to get farmers in China to adopt soil carbon sequestration measures?
	Who stands to benefit from this method or policy?	Which companies and groups are supporting the Californian afforestation initiatives? Why?
	How would the assessment of this method change under **different socioeconomic assumptions about the future**?	How would the social impacts of BECCS change if global population follows the lowest UN projections?
	How would this method **interact with other methods**?	How would the environmental and social impacts of removing one billion tons of CO_2 per year with BECCS change if global afforestation is removing 500 million tons of CO_2 per year at the same time?
	How would this method fit into various possible **portfolios of emissions abatement technologies and carbon removal technologies and practices**?	How would ocean alkalinization fit into a world in which energy comes mainly from solar and wind and carbon removal is implemented mainly by afforestation, enhanced mineralization, and DACCS?

6. Conclusion

A decade's worth of research strongly suggests that carbon removal will be necessary to achieve the ambitious goals the world set for itself in the Paris Agreement. The next decade of research needs to refine our understanding of the various options for carbon removal so that societies can decide if, when, and how to incorporate carbon removal into their own long-term mitigation strategies. Different methods of carbon removal create different opportunities, bring different co-benefits, and face different limitations and downsides. To ensure that research and development efforts are responsive to societal needs, they should inform and be informed by broad societal conversations about how carbon removal fits into broader climate policy portfolios, both nationally and internationally.

This report argues that all forms of carbon removal count as mitigation, but that not all mitigation is equally good. Some methods of carbon removal may prove unacceptable or infeasible, and some will prove more appropriate for some circumstances than for others. And crucially, recognizing carbon removal as a kind of mitigation does not mean giving up on emissions reductions; because carbon removal cannot keep up with current rates of greenhouse gas emissions, among other reasons, societies would be foolish to rely on carbon removal rather than emissions reductions. The questions societies must confront, therefore, are about which methods of carbon removal are most effective in their present or future circumstances, what side effects various methods would have in those circumstances, and how the relevant methods fit into their larger mitigation strategies. As answers to these questions begin to come into focus, societies can begin upscaling appropriate methods of carbon removal to help fight climate change.

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Institute for Carbon Removal Law and Policy

As a supplement to cutting greenhouse gas emissions, the world could further reduce climate risk by actively removing carbon dioxide from the atmosphere. The Institute for Carbon Removal Law and Policy is dedicated to assessing the social, legal, ethical, and political implications of carbon removal technologies and practices and to facilitating engagement on these issues by key stakeholders and the public. The Institute is an initiative of the School of International Service at American University in Washington, DC.

Why Talk About Carbon Removal?

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