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A PROGRESSIVE PLATFORM FOR CARBON REMOVAL

# Guiding Principles

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# INTRODUCTION

## TO NET-ZERO AND BEYOND: THE PRESSING NEED FOR CARBON REMOVAL

The climate crisis is already wreaking havoc on the United States. In 2020 alone, megafires on the west coast ravaged over eight million acres of land, killing close to 50 people and destroying over 10,000 buildings — the worst fire season ever recorded. In the southeast, hurricane season was the most severe in over 100 years, with a record twelve named storms making landfall. “Natural” disasters have become more frequent and more severe as the climate changes. They bring with them unprecedented destruction of property and ecosystems, and loss of human lives. For poor people and people of color, these disasters have been magnified by existing structural inequalities which put their communities at greater risk.

In addition to losing lives and livelihoods, and amidst one of the worst recessions in recent history, Americans have also borne the economic burden of the climate crisis. New research shows that the 2018 wildfire season, one of the worst on record, cost American taxpayers $148.5 billion, approximately 0.5 percent of annual GDP.[1] Last year, hurricane season cost taxpayers more than $20 billion.[2] This is only the beginning. If the climate crisis is permitted to accelerate under business as usual scenarios, the consequences — economic, social, and environmental — will be crippling.

One of the most significant undertakings will be to decarbonize the American economy, as our flagship blueprint for a Green New Deal and other climate policy reports lay out. But because policymakers have resisted bold climate action for decades, decarbonization alone is no longer enough. Because $CO_2$ is long-lived and can remain in the atmosphere for centuries, research shows that society’s emissions to-date have paved the way for warming of 2.5 to 3°C above preindustrial levels — far exceeding the targets laid out in the international Paris Climate Agreement. This is assuming all countries meet their individual Paris Agreement goals, which most — including the U.S. — are not on track to do.

Generations of inaction have left current and future policymakers with little choice but to pursue actions that rapidly accelerate emissions reductions while also removing past emissions from the atmosphere to achieve net-zero emissions and ultimately net-negative emissions. Even optimistic scenarios in global climate models now require the use of carbon removal technologies and practices (also referred to as “net-negative emissions”), which decrease greenhouse gasses already in the atmosphere, in order to meet global climate goals. In its *Special Report on Global Warming of 1.5°C*, the IPCC estimates a need for the secure removal of 348 to 1,218 gigatons of carbon dioxide-equivalent emissions by the end of the century, approximately 10 to 25 years’ worth of current global emissions.[3] However, many scientists question the feasibility of removing carbon at this scale, advancing instead a more limited carbon removal target, especially for the first half of the 21st century. The first step will be to achieve carbon removal capacity equal to “hard-to-abate” emissions: those from industries like aviation, cement, and steel that society relies on but are difficult to decarbonize with existing technologies.

Annual hard-to-abate emissions are estimated at 1.5 to 3.1 Gt of carbon dioxide equivalent, or 3.5 to 7.3 percent of CO2 emissions in 2019.[4] The exact value within this range will depend, of course, on how quickly and ambitiously countries decarbonize — a critical complement to net-negative emissions. Minimizing the amount of residual emissions (those that are not eliminated) and specific targets by sector are therefore critical co-requisites with carbon removal. While striving to reduce residual emissions, the U.S. should set initial targets for carbon removal to counterbalance global residual emissions, as we describe in our *Federal Action Plan* report. As the largest cumulative emitter in global history, the U.S. has a responsibility to shoulder a large share of this emissions removal burden. Beyond righting historic wrongs, a large-scale carbon removal project by developed countries in the Global North like the U.S. could also provide developing countries in the Global South with much-needed flexibility to grow their economies — a luxury that western governments have long enjoyed.

The scale of carbon removal and decarbonization necessary also provides unique opportunities for a green recovery from the COVID economic crisis. In addition to expanding unemployment benefits and providing immediate financial relief, the federal government must launch large-scale green recovery programs that create jobs, build resilient infrastructure, and transition the U.S. away from fossil fuels, as Data for Progress has outlined in our A Clean Jumpstart for America report, co-published with Evergreen Action. The Biden Administration's American Jobs Plan presents exciting opportunities to do this work. In addition to advancing clean energy access, net-negative emissions technologies and practices should play an important part of the green recovery. Doing so could create thousands of well-paying jobs distributed across the country. Moreover, communities previously embedded in the fossil fuel economy in many instances will possess the very skills necessary to permanently store carbon pollution, presenting opportunities for a just transition.

As we detail in this report, carbon removal can be accomplished through a wide variety of approaches, and it is critical that policies such as the American Jobs Plan and Congressional infrastructure legislation focus on advancing many different strategies in tandem. Policies to jumpstart a new carbon economy must also build upon the principles of the Green New Deal — unlike the vision of carbon removal advanced by oil and gas giants, a progressive net-negative emissions platform would not extend the lifetime of fossil fuels. Instead, it would create well-paying, unionized jobs and benefit the communities that have borne the brunt of climate and environmental destruction: communities of color, Indigenous communities, poor communities, blue collar workers, and fenceline communities. Our progressive platform also lays the groundwork for carbon removal as a public utility rather than a private enterprise, underscoring the U.S. government's responsibility to address its long legacy of climate-warming emissions. To equitably and effectively stave off the worst effects of the climate crisis, the federal government must deal with the problem of legacy carbon dioxide waste[5] and build a diversified network of public infrastructure to clean up climate-warming pollution, as detailed in this report and its *Federal Action Plan* companion.

# SECTION 1. Laying the Foundation for a Progressive Carbon Removal Strategy

Carbon removal strategies — also referred to as [net-]negative emissions technologies and practices, [net-]negative emissions, greenhouse gas removal (GGR), and carbon dioxide removal (CDR) — encompass a diverse suite of climate solutions. In recent years, recognition of their importance to meeting climate goals has led to the rapid expansion of carbon removal-related research and demonstration projects. Carbon removal's basic purpose is to remove excess carbon from the atmosphere — carbon that is already triggering climate feedback loops that could push us beyond 1.5 or even 2°C.

The crux of a progressive net-negative emissions strategy should be to address the climate crisis ambitiously, rapidly, and equitably. As with other areas of federal innovation, the development of carbon removal infrastructure should:

1. Expand the federal innovation apparatus to include diversified, complementary approaches to achieve a net-zero and then net-negative emissions U.S. economy.
2. Reduce the cost and improve the performance of technologies and strategies so that carbon removal can be used widely and rapidly.
3. Combat historic, structural injustices including unequal access to clean environments, economic opportunity, public health, and climate resilience.
4. Lay the groundwork for a future where carbon removal becomes a public utility, and the jobs it creates are quality, unionized jobs that pay family-sustaining wages.

## ESTABLISHING A PROGRESSIVE DEFINITION FOR CARBON REMOVAL

Despite carbon removal's rise to political prominence, the public as a whole remains uncertain of what does and does not constitute net-negative emissions. Seventy-three percent of Americans have had little to no exposure to the subject and a significant portion mis-identify recycling, geothermal power, and natural gas as carbon removal.[6] Indeed, the very meanings of "negative" and "removal" remain a matter of debate, including among scientists. For example, how long must emissions be stored to be considered permanent? Should projects that prevent or reduce emissions be counted toward carbon removal goals? And what of the projects that draw down carbon in one place but trigger increased emissions in another?

Differing responses to the questions above have yielded numerous and often conflicting definitions for carbon removal and net-negative emissions (used here interchangeably). Many have been developed and advanced by fossil fuel companies in order to greenwash their declining industry. Predictably, fossil fuel giants' definitions of carbon removal promote continued — and often even expanded — fossil fuel use. Media campaigns by well-funded industry groups have led many progressives to associate carbon removal with fossil fuel interests, causing them to instinctively mistrust or even oppose them outright. There is good reason for this mistrust: continued fossil fuel use spells climate disaster, and if companies are able to control the narrative of what net-negative emissions are and how they can be accomplished, then true climate action could very well remain out of reach.

**A progressive net-negative emissions strategy must not serve as an excuse to continue reliance on fossil fuels nor to deter swift, bold transitions away from our petro-carbon economy.** Consequently, it is vital that carbon removal technologies and practices permanently reverse past emissions, rather than simply prevent or limit new emissions. Technologies that do not meet this definition should not be considered part of a net-negative emissions strategy.

Further, four principles that are increasingly used by the scientific community to define carbon removal must also be upheld[7]:

1. Greenhouse gases are removed from the atmosphere.
2. The removed greenhouse gases are stored out of the atmosphere in a manner intended to be permanent, and monitored to ensure permanence.
3. Upstream and downstream greenhouse gas emissions associated with the removal and storage process, such as emissions from land use change, energy use, unintended emissions from industrial processes, gas fate, and co-product fate, are comprehensively estimated and included in the emission balance.
4. The total quantity of atmospheric greenhouse gases removed and permanently stored is greater than the total quantity of greenhouse gases emitted to the atmosphere.

## WHAT PROGRESSIVE CARBON REMOVAL IS NOT

As progressives work to advance a broad portfolio of climate solutions, we must also be clear on what should *not* constitute carbon removal. This includes a number of technologies and practices that are either misinterpreted by or misrepresented to the public as carbon removal. Some of these are useful tools to meet societal needs; indeed, some will even be necessary to achieve climate goals. However, transparency and accountability in meeting net-zero and net-negative emissions targets requires that carbon removal be distinguished from other tools — and, of course, from greenwashing. The following is a list of some of the technologies and practices that are often confused with or greenwashed as carbon removal.

- **Enhanced oil recovery** (EOR) uses pressurized carbon dioxide to force hydrocarbons from near-depleted wells, trapping the injected $CO_2$ in geologic formations from which oil was extracted. According to analysis conducted by the International Energy Agency (IEA), EOR is capable of storing an average 0.63 tonnes of $CO_2$ more than it uses, so can theoretically result in net-negative emissions.[8] However, the majority (more than 70 percent) of $CO_2$ currently used for EOR in the U.S. is extracted from underground rather than captured from industry,[9] and therefore cannot be considered carbon removal or even emissions reduction. Most importantly, EOR does not address toxic air and water pollution burdens on environmental justice communities. By delaying the sunsetting of fossil fuel infrastructure and the industry's political power, EOR in its present form perpetuates a petro-carbon economy and is therefore likely to increase global emissions overall. At best, EOR might be considered a carbon reduction measure, but is poorly aligned with a progressive definition of carbon removal.[10] At worst, EOR and the provisions of the 45Q tax credit that incentivizes it might be considered a fossil fuel subsidy.

- **Carbon capture, utilization and/or storage** (CCS/CCUS) technologies can be affixed to large point-source emitters like power plants, cement production, and other carbon-intensive industries, capturing emissions at the smokestack. CCS and CCUS can be useful tools for decarbonizing the economy, minimizing emissions from sectors that are societally useful but difficult to decarbonize such as heavy shipping, aviation, and the production of steel and cement. For industries like these for which society has few viable alternatives, CCS's capacity to reduce 37 percent of lifetime emissions should not be overlooked.[11] However, CCS does not remove more emissions than the facilities it is attached to produce overall, and so cannot be considered carbon removal. Further, progressives must take care to differentiate the important uses of CCS technology from fossil fuel greenwashing, which presents CCS as a way for fossil energy to be "climate-friendly." While CCS should likely play a role in progressives' overall climate strategy, we must be clear that this technology should be treated as an emissions reduction measure and should not permit the continuation of the petro-carbon economy.

- **Ecosystem protection** — including forests, wetlands and peatlands — is imperative for biodiversity preservation. Intact ecosystems provide innumerable services to society, from fostering healthy food systems to recreation to maintaining buildings' structural integrity. They are also the cornerstones of a healthy natural world — important, many would argue, beyond what they provide society. In short, there are many compelling reasons to protect nature. However, preventing ecosystem destruction or deterioration serves to maintain their carbon stocks rather than remove additional carbon, and so should be considered emissions avoidance. This is different from active measures to enhance ecosystems' and agricultural lands' ability to uptake carbon, which are discussed later in this report as potential carbon removal options.

- **Short-term soil carbon enhancement** refers to soil health practices — often employed by farmers — meant to maximize carbon stored underground. As will be discussed later in this report, employing these strategies can constitute net-negative emissions. However, many are used for only short periods of time, such as a growing season, and then go out of use temporarily or permanently. When they do, carbon stored in soils is released back into the atmosphere and thus cannot be considered meaningful carbon removal.[12] Similar challenges exist with forestry-based carbon removal, which will also be discussed later in this report.

While some of these strategies are important to holistic environmental policy, they do not meet the permanent removal requirement of net-negative emissions. For example, preserving natural systems like wetlands and forests offers myriad benefits, including protecting ecosystems' carbon stores. However, these measures prevent the release of emissions rather than address past emissions, and so are more aptly categorized as avoided emissions. Further, we affirm that carbon capture and storage is likely to be a key technology for offsetting sectors that are difficult to decarbonize; however, because CCS aims to prevent a portion of point-source emissions, it too should be considered an emissions reduction measure.

## CARBON REMOVAL STRATEGIES ARE ALREADY HERE

Carbon removal is often portrayed in popular media as "unproven" and/or "future technologies" — little more than figments of the scientific imagination. Fortunately, this is not so. While carbon removal will benefit from additional RD&D, methods discussed in this report have been studied using models and, increasingly, field trials and demonstration projects. For example, although solutions like direct air capture (DAC) and bioenergy with carbon capture and storage (BECCS) are in early stages of development, more than a dozen DAC facilities and demonstration projects already exist around the world.[13] The most recent of them — under construction in Iceland — will be capable of securely removing 4,000 tons of $CO_2$ per year. The modular design of this facility, the largest in the world, allows it to be constructed in under two years, which is faster than most infrastructure projects of that scale and novelty.[14] This is not to say that carbon removal can be deployed at-scale tomorrow. Carbon removal will require more research and staged deployment before it reaches climate-relevant scales. However, solar and wind power's rapid cost declines in the past two centuries have shown us that climate solutions can go from incubation to deployment in very little time provided the right level of government investment and regulatory support. Progressive carbon removal policy should therefore focus on research, development, and demonstration in the near term to ensure that it is ready for at-scale deployment in coming decades.

## THE DANGER OF RELYING EXCLUSIVELY ON "NATURE-BASED" SOLUTIONS

Research on negative emissions technologies and practices has taken off in recent years and with it, the diversity of carbon removal options. Most of the public's attention, however, has focused on so-called "nature-based" solutions: a term usually meant to describe soil carbon enhancement, reforestation, and restoration of other ecosystems (described in Section 2). They are often sold as win-win-win approaches: good for people, good for profits, and good for the planet. Although biological solutions like these are important, their carbon removal potential is often misrepresented by companies hoping to continue business as usual. This is largely played out in offset markets, which allow companies to pay other entities for sustainable behavior that they — the company — can then claim as "credits" to count toward their net-zero goals. Beyond providing companies an excuse to continue polluting, these credits often fall short on their promises of preventing and/or removing emissions.[15]

For example, under current regulation, a corporation might pay a logging company not to cut down a forested plot for a set amount of time. This period of time would be laid out in a contract, typically on the order of a few years or perhaps even a few decades, during which time the forest would be left standing. If after the contract period the logging company cuts down the forest and its stored carbon is released, the company maintains its credits without assuring that they still represent their carbon value. Similarly, if the logging company under contract preserves one patch of forest because they are paid to but then cuts down another patch of forest to make up their annual timber quota, the company has been allowed to pollute as normal while the logging company has cut down the same amount of forest, albeit in a different location.[16]

Indeed, these problems have played out in several high-profile projects. Of greatest international note is the REDD+ program: a multilateral effort led by the United Nations to create a global offsets market. The intention was to pay people in developing countries to act as stewards of conservation, especially forests, instead of relying on livelihoods that involved destroying these ecosystems. The outcome was much grimmer, riddled with government corruption, lack of transparency and, often, disregard for workers' rights.[17] Further, the California offsets market has demonstrated how volatile biological carbon storage can be in a warming climate. As wildfires ravaged the west coast in 2020, a significant portion of the state's carbon credits went up in smoke.[18] Science tells us that wildfires and other natural disasters are growing stronger, less predictable, and more frequent; it will therefore be dangerous to rely solely on forests and soils to draw down carbon. It will also be critical that these options' costs reflect the risks associated with them: long-term maintenance and, in the event of a disaster, replacement. Adding in these expenses, nature-based solutions are revealed not to be the low-cost options they may seem.[19] They will have to be part of a larger toolbox of carbon removal.

Beyond allowing corporations to greenwash their way out of serious decarbonization, limiting carbon removal to a few biological approaches is bad climate policy. The Sierra Club, long resistant to non-biological carbon removal,[20] recently released a report acknowledging that "natural systems can probably only draw down carbon by 5 gigatons per year worldwide without severely impacting food production or causing significant equity issues."[21] As progressives work to realize large-scale carbon removal, it is incumbent upon us to rely on a wide array of approaches — biological, chemical, and hybrid — while emphasizing non-biological approaches for long-term stability. Further, the idea of biological "carbon offsets," while likely well-intentioned, have been demonstrated to be bad climate policy. As we move forward, it will be important to clearly delineate negative emissions, and distance them from offsets.[22]

## SECTION 2. An Extensive Menu of Options

At their core, net-negative emissions technologies and practices expand, accelerate, and/or mimic natural processes for cycling carbon. Carbon removal is typically categorized by its means of capturing emissions: biological, chemical, and hybrid processes. Biological approaches typically rely on photosynthesis to convert gaseous carbon to be stored in soils and/or biomass, such as planting new forests or managing soils to take up carbon. Chemical approaches react with carbon molecules so that they can be captured and/or stored underground, in the deep ocean, or even converted into long-lived products like building materials. Direct air capture and enhanced weathering are two examples of chemical approaches. Hybrid methods take advantage of photosynthetic carbon uptake like biological approaches do but rely on a chemical process — often combustion — to capture emissions, which can then be stored in soils or geologic formations. As mentioned in section 1, new net-negative emissions methods are rapidly being proposed and tested. This list of strategies is non-exhaustive and meant to reflect those that presently show the greatest promise.

## STRATEGY 1: BIOCHAR – HYBRID

Biomass (living matter) is an important store of carbon, taken in from the atmosphere via photosynthesis by plants, algae, and cyanobacteria. Through a chemical reaction called pyrolysis, in which organic material is heated in low- to no-oxygen conditions, biomass can be transformed into a solid that does not break down for hundreds of years. This solid, referred to as "biochar", holds the carbon originally trapped through photosynthesis, preventing it from being re-released when the biomass decomposes or is burned. In addition to storing carbon, pyrolysis lets off heat, which can be captured and used for clean energy. As with all approaches to net-negative emissions, location will be key to maximizing benefits and co-benefits. Depending on where it is implemented, biochar can be mixed into soils to provide additional benefits: better water retention, improved nutrient flows, and increased plant growth. Biochar shows promise in many regions of the U.S.[23] Estimates for biochar's contribution to carbon removal vary from 0.5 to 2 Gt per year by 2050,[25] and its estimated costs range from $18 to $166 per ton removed.[24]

## STRATEGY 2: BIOENERGY WITH CARBON CAPTURE AND STORAGE – HYBRID

Bioenergy with carbon capture and storage (BECCS) is the most prominent method of removing atmospheric carbon in IPCC climate scenarios, which assume 5 to 10 gigatonnes of $CO_2$ per year via BECCS by 2100 in order to meet 1.5 or even 2°C. Given BECCS' prominence in integrated assessment models like those used by the IPCC, this strategy is largely responsible for the recent surge in public discussion on carbon removal approaches as a whole. BECCS comprises two stages. The first is producing bioenergy. Many approaches rely on waste biomass (i.e. non-food parts of crops, leaves from timber trees, etc.), and others involve cultivating plants that grow quickly and store carbon efficiently in their soils and biomass. Harvested biomass is then combusted to produce bioenergy, and emissions from combustion are captured before entering the atmosphere. These emissions can then be stored in geologic formations or long-lived products. Although disagreement remains on how large a role BECCS should play in global negative emissions (with IPCC estimates on the higher end), meta-analysis suggests that BECCS has the capacity to safely remove 0.5 to 2Gt of $CO_2$ per year by 2050.[25] Achieving higher levels of carbon removal is technically possible but would require large amounts of land and freshwater and could therefore threaten food production and biodiversity.[26] Modelling of BECCS potential in the U.S. shows a lack of carbon transport infrastructure and suitable land, which limits national capacity to approximately 100 Mt $CO_2$ per year.[27]

## STRATEGY 3: DIRECT AIR CAPTURE – CHEMICAL

Direct air capture (DAC) pulls carbon pollution straight from the atmosphere. Unlike CCS, which captures pollution as it leaves smokestacks, DAC filters ambient air to remove its dilute concentrations of $CO_2$. As air passes through DAC technology, chemical reactions selectively bind $CO_2$ to remove it. The captured carbon pollution is then compressed and pumped into deep geologic formations for long-term storage. It can also be used to help decarbonize hard-to-abate sectors. For example, carbon dioxide can be converted into fuels for aviation and heavy shipping, or to produce more sustainable cement. While "air-to-fuels" and low-carbon cement are useful climate strategies, it is important to note that they are not themselves negative emissions strategies — unless the carbon is permanently removed from the atmosphere, these measures more closely resemble resource recycling. One of the primary challenges facing DAC is its high costs, which currently range upwards of $600 per ton without government incentives and closer to $200 per ton with significant incentives. These costs could, however, be significantly lowered. With sufficient investment, costs could reach $100 to $200 per ton within 5 to 10 years.[28] Indeed, pilot-scale facilities already promise costs of $94 to $232 per ton, and are expected to drop below $60 by 2040.[29] Expert assessment places DAC's global removal potential at 0.5 to 5 Gt of carbon dioxide emissions annually.[30]

## STRATEGY 4: ENHANCED WEATHERING – CHEMICAL

Rocks are an important part of the Earth's carbon cycle. Through a series of chemical reactions, carbon from the atmosphere makes its way into the ocean via rock, where it is stored for millions of years. Already, the weathering process converts approximately one billion tons of atmospheric $CO_2$ into rock each year. This cycle, however, takes between 100 and 200 million years to complete — orders of magnitude longer than we have to fix climate change.[31] Enhanced weathering is a method of accelerating this natural process so that it can abate climate change in the near term. To do so, rocks prone to weathering are crushed and scattered along land. These include waste products from mining, steelmaking, and other industrial activities, as well as abundant minerals such as olivine and basalt. Crushing the rocks increases their surface area, creating more space for them to react with $CO_2$ in the air. Research indicates that enhanced weathering could improve soil quality and could provide negative emissions of 2 to 4 Gt per year by 2050,[30] and further scaled to achieve a cumulative 100 to 367 Gt $CO_2$ this century — up to 30 percent of the world's maximum carbon removal needs. Current costs range from $50 to $200 per ton of $CO_2$. Because this method is suited to regions that are warm and humid, it should only be employed in select parts of the United States. Further, caution would be required when dealing with mine tailings and other waste streams, and fine particulates that could be harmful if inhaled.[32]

## STRATEGY 5: FORESTATION (REFORESTATION & AFFORESTATION) – BIOLOGICAL

Forests are often referred to as the "earth's lungs" for their role in carbon uptake and oxygen production. Internationally, forest conservation is recognized as a critical climate change mitigation strategy. It is estimated that deforestation is responsible for up to 10 percent of global emissions.[33] In addition to protecting forests, reforestation (replanting forests that have been destroyed or degraded) and afforestation (planting forests where none previously existed) are increasingly popular mechanisms for addressing the climate crisis. (Who will soon forget President Donald Trump's 'Trillion Trees' gimmick?). As discussed in Section 1, however, challenges arise when evaluating forests for carbon removal. Chiefly, forestry-based measures often do not remove carbon pollution in excess of what would have been removed without intervention. Further, care must be taken to ensure permanence of carbon removed; forest fires, change in land use, pests, and other risks exacerbated by climate change would need to be carefully and consistently monitored to prevent reversal. Special caution should be taken with afforestation, which presents the risk of lowering albedo and increasing global warming. If it is correctly implemented, forestation can be an important part of the carbon removal portfolio. By 2050, its removal potential is up to 5 gigatons per year, but many experts expect it to be much lower.[34] The sticker costs of forestation are low relative to other carbon removal options, ranging from $5 to $100 per ton, though afforestation costs may be as high at $200 per ton.[35,36] Actual costs of forestation projects may be much higher when insurance, monitoring, and replacement costs are incorporated.

## STRATEGY 6: OCEAN ALKALINITY ENHANCEMENT – CHEMICAL

The ocean has absorbed nearly one-third of anthropogenic carbon emissions since the mid-'90s, a fourfold increase since the beginning of the Industrial Revolution.[37] Ocean alkalinity enhancement (OAE) is a form of weathering that takes place in seawater, accelerating the ocean's uptake of carbon. It involves adding alkaline substances (those able to resist acidification) such as olivine or basalt. These substances react with seawater, causing its pH to rise (become less acidic). This changes the carbonate chemistry, leading surface waters to absorb more $CO_2$ from the atmosphere. Carbon dioxide removed via this method will be kept out of the atmosphere for approximately 10,000 years.[38] In addition to drawing down atmospheric carbon for permanent storage, OAE could help conserve coral reefs and other calcifying marine organisms. By increasing the alkalinity of seawater, localized effects of anthropogenic ocean acidification can be reversed, which could allow fragile coral reefs to become more resilient to climate change effects like coral bleaching. However, OAE also has the potential to release metals like nickel and chromium and can create overly-alkaline conditions, which could harm instead of help some species. Carbon removal via ocean alkalinity enhancement is estimated to cost between $3 (for the methods that co-produce hydrogen) and $160 per ton. Although OAE is not yet ready to be deployed at large scale, it shows promise for securely removing several gigatons of $CO_2$ per year.[39]

## STRATEGY 7: SOIL CARBON SEQUESTRATION – BIOLOGICAL

Soils contain three times as much carbon as the atmosphere, and are an important part of the global carbon cycle. Changing land use practices over the past 10,000 years have degraded soils, however, releasing 840 Gt of carbon dioxide. Human use has also left soils less able to uptake and retain carbon. Just as these natural "carbon sinks" have been weakened by human mismanagement, they can be enhanced to store additional carbon. Farmers and ranchers can thus play an important role in removing atmospheric carbon by implementing practices such as low- or no-till soil management, planting perennial crops, planting cover crops to avoid leaving fields fallow, enhancing soil nutrient content, and rotating cattle grazing. Ambitious estimates indicate that, if scaled up dramatically, soil carbon practices could potentially sequester 0.5 to 5 Gt of carbon dioxide annually by 2050 at a cost of $0 to $100 per ton. Cumulatively, this could amount to 104 - 130 Gt of carbon by 2100.[40] Besides potential climate benefits, soil carbon management can yield healthier soils, increased yields, and other benefits to farmers and landowners. It is also an important step in transitioning agriculture for climate resilience, and in promoting biodiversity on- and off-farm. Many experts call into question whether soil carbon enhancement can produce promised scalable climate benefits at all.[41] This is because delivering soil carbon management as an effective carbon removal would require long-term contracts (i.e. upward of 100 years) with farmers and land-owners, which are implausible in most cases, to ensure they do not change practices after a few years as most currently do. Secure removals would also require careful monitoring to ensure permanent removal, as soil-based carbon removal is volatile to reversal: if land use practices change, or climate-induced changes occur (i.e. natural disasters), carbon stored can be released.

Further, "saturation points" — the points at which soils are so overloaded with carbon that they begin to re-emit stored carbon into the atmosphere — are a concern.[42]

## "ADD-ON" STRATEGY: MACRO- AND MICROALGAE – BIOLOGICAL, HYBRID

Oceans play an indispensable role in climate regulation and, increasingly, in mitigating anthropogenic climate change. Each year, the ocean is responsible for drawing down roughly one-third of anthropogenic emissions, relying heavily on algae. Algae are some of the world's most efficient photosynthesizers and power the ocean's "biological carbon pump," which cycles atmospheric carbon into the deep ocean for long-term storage.[43] As such, algae present myriad opportunities to aid in large-scale carbon removal efforts. For example, research indicates that combining microalgae production with BECCS can improve system efficiency, and that macroalgae biomass itself can be used as a fast-growing, low-cost BECCS feedstock. Biological carbon removal approaches like forestation have also been proposed in coastal environments to increase "blue carbon" stocks, although it is worth noting that the ocean area suitable for these activities is relatively small.[44]

## SUMMARY OF OPTIONS

Across all carbon removal strategies, great uncertainty remains on large-scale potential, and so research and development will be critical to fill gaps in knowledge. To best complement decarbonization efforts, the U.S. must begin developing its capacity to remove carbon from the atmosphere in the immediate term and begin to roll out projects in phased development. The following summary table represents estimates for how much carbon each of the strategies discussed might be able to safely remove globally.[45]

| CARBON REMOVAL STRATEGY | COST ($/TON) | REMOVAL POTENTIAL (GT/YEAR) | CO-BENEFITS | RISKS |
|---|---|---|---|---|
| **Biochar** | 18 - 166 | 0.5 - 2 | Improved soil health; Energy production | Reversibility, if soils are disturbed |
| **Bioenergy with CCS** | 20 - 100 | 0.5 - 5 | Bioenergy production | Land use requirements |
| **Direct Air Capture** | 94 - 600 | 0.5 - 5 | Fuel production | Costs; Energy requirements |
| **Forestation** | 5 - 200 | 0.5 - 3.6 | Biodiversity promotion | Reversibility; Double-counting; Land grabbing; Decreased albedo |
| **Enhanced Weathering** | 50 - 200 | 2 - 4 | Improved soil health | Mineral mining and waste; Particulate matter |
| **Ocean Alkalinity Enhancement** | 3 - 160 | Many | Countering ocean acidification; Hydrogen production | Mineral mining; Changes to ocean ecosystems |
| **Soil Carbon** | 0 - 100 | 0.5 - 5 | Improved soil health | Reversibility; Double-counting |

# SECTION 3. Guiding Principles for Progressive Carbon Removal Policymaking

## HIGH-LEVEL POLICY PROPOSALS

As this report lays out, negative emissions are a critical component of bold climate action. To meet President Biden's pledge to reduce emissions 50 percent by 2030 and achieve net-zero by 2050,[46] the U.S. will need to ambitiously transition its electricity supply to clean energy, invest in low- and no-emissions public transportation, update housing stocks with weatherization and efficient building materials, and address energy inequality and poverty. It must also work to build its ability to remove carbon from the atmosphere to complement rapid decarbonization. We recommend Congress and the Executive take a comprehensive approach to climate policy by adhering to the following guiding principles:

1. **Negative emissions targets must be set separately from and additional to mitigation, adaptation, and biodiversity targets.** Distinguishing between these targets will be critical to assuage worries that negative emissions might distract from decarbonization or threaten biodiversity. We recognize that projects may crosscut these goals; therefore, comprehensive congressional and executive guidance on meeting and accounting for these targets will be critical to ensuring that the U.S. advances holistic climate policy. Moreover, presenting a clear framework for separate but complementary climate goals will pave the way for U.S. leadership as the country re-engages with the international community on climate policy.

2. **The U.S. must contribute its fair share to global negative emissions needs, while promoting fairness at home.** After years of dirty industrialization, the U.S. has contributed 25 percent of global cumulative emissions, making ours the largest carbon footprint in the world.[47] As developing countries strive toward better lives and livelihoods, it is a matter of global justice that the U.S. cleans up its fair share of carbon pollution — especially recognizing the U.S.'s imperial history at home and abroad. As the U.S. works to right international wrongs, lawmakers must also recognize that poor and BIPOC communities have contributed the least to the climate crisis and have been affected the most; policies that address removing emissions must also work to alleviate structural inequalities domestically. This will include moving beyond removing carbon pollution from the atmosphere to cleaning up other deadly forms of air pollution that disproportionately burden environmental justice communities. It will also mean ensuring that fossil fuel infrastructure is rapidly decommissioned, not allowing carbon removal to be a lifeline for a dying industry.

3. **Investment should reflect the level of urgency of the climate crisis and propel the U.S. into global leadership on carbon removal.** The world has less than a decade to stave off the worst effects of the climate crisis, and it is not currently on track to do so. The U.S. has the largest economy in the world, but still lags behind most developed countries in RD&D spending relative to size.[48] As part of its green recovery from the COVID economic crisis, the UK's Energy White Paper pledged to spend £1 billion (~$1.36 billion) in carbon capture, utilization, and storage between 2021 and 2025.[49] The U.S., in its year-end COVID recovery package, allocated $447 million for all of carbon removal despite having an economy seven times larger that the UK's in terms of GDP.

4. **The federal government should immediately invest in RD&D for negative emissions technologies and practices at the gigaton-scale.** In order to reap the benefits of early investment in carbon removal approaches, including high-quality union jobs and economic gains, the U.S. must act now. Congress should allocate annual carbon removal RD&D budgets that compete with — if not exceed — major innovations in previous decades: renewable energy, the space program, and perhaps most fittingly fossil energy. Some approaches should begin staged deployment to better understand their carbon removal potentials in the U.S. Others, like DAC, should be boosted with large-scale demonstration projects. In every case, the U.S. should strive to accelerate innovation, bring down costs, and model solutions to carbon pollution after public utilities.

5. **Federal investments in carbon removal must prioritize a public option.** Just as the U.S. has done for Superfund sites, the federal government should establish a centralized system for managing greenhouse gases as waste.[50] As discussed, negative emissions should be pursued in tandem with ambitious decarbonization; a public option for carbon removal would allow for coordinated ambition in both areas of climate action. It would also enable Congress to build in equity and community benefit mandates, such as requirements for worker unionization.

## CHECKLIST FOR PROGRESSIVE CARBON REMOVAL POLICYMAKING

✓ When evaluating policy proposals, lawmakers in legislative and executive branches should refer to the following questions, attempting to maximize the number of "yes" responses.

✓ Does it permanently and securely remove past emissions from the atmosphere, to count toward a national negative emissions target?

✓ Does it create high-paying, long-lasting, accessible, unionized jobs with healthcare that require little to no training? **OR** Does it create high-paying, long-lasting, accessible, unionized jobs with healthcare that include robust training programs for prospective workers?

✓ Does it require community consultation, participation, and buy-in throughout project development and deployment?

✓ Does it emphasize and maximize public ownership, paving the way for a public option, while setting strict standards for private participation?

✓ Does it incentivize creating jobs for traditionally underserved communities, including poor, frontline, and BIPOC communities?

✓ Does it include mechanisms to maximize job continuation and retention in traditionally underserved communities, including poor, frontline, and BIPOC communities?

✓ Does it take into account cumulative environmental impacts on communities and attempt where possible to ameliorate legacy air pollutants in addition to greenhouse gases, especially those that impact human health?

✓ Does it honor and prioritize indigenous peoples' sovereignty and right to government-to-government consultation?

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