Roads to Removal – Part 1

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1. Introduction

As happens occasionally, this paper has grown beyond the length that I'm comfortable with, and thus I broke it into two posts.

I have written several papers on this subject in the past. The title of this paper features the word "Removal." This refers to greenhouse gas (GHG) removal from the atmosphere. It is important to stop emitting GHG, but this is not sufficient to mitigate climate change, even if we exceed all estimates as to how rapidly we can perform this.

I tend to call GHG Removal "Negative Emissions Technology (NET or NETWORKS), and I have been advocating these actions since I wrote a three-part series on it:

New NETWORKS, Part 1: BECCS: *This post covers sources of biomass that have the potential contribute to carbon dioxide sequestration while fulfilling other human needs.*

https://energycentral.com/c/ec/new-networks-part-1-beccs

New NETWORKS, Part 2: Mineralization for GHG Capture: *This paper covers several potential methods using mineral incorporation (a.k.a. mineralization) to store and/or permanently sequester carbon dioxide (CO_2), the main greenhouse gas (GHG). Section 2 is about a simple process that will combine two hazardous industrial wastes, alkaline mineral waste and carbon dioxide (CO_2). This process creates a stable mineral that can be safely buried or perhaps used in long-lived structures. Others that are described in section 3 are similar methods already in use.*

https://energycentral.com/c/ec/new-networks-part-2-mineralization-ghg-capture

New NETWORKS, Part 3: Two Solutions: *California has two challenges. One is the yearly batch of wildfires that keep getting worse every year. In 2020 the acreage burned was more than double any previous year, and other metrics were similarly dire.*

The other challenge is that we have the most ambitious goals for mitigating climate change in the U.S. One might think that the challenge from wildfires would be detrimental to our climate change goals, and indeed in most ways it is, but there is at least one synergy between these as described in the following paper.

https://energycentral.com/c/cp/new-networks-part-3-two-solutions

In 2020, my viewpoint that the GHG removal would be needed in the long run was a minority opinion. Most thought that simply ceasing the emission of GHG was sufficient. Now the consensus is strongly shifted to the viewpoint that GHG removal will be necessary, even among the most respected research institutions in the U.S.

There is an urgent need to remove carbon dioxide (CO_2) from the atmosphere to ensure climate security and resilience. In 2022, the United States set a goal of developing carbon dioxide removal (CDR) pathways that will remove CO_2 from the atmosphere and store it at the gigaton scale (at least a billion tonnes per year). [1]

[1] A large number of authors / institutions created this large document, Click on "Team" in the main document for details, "Roads to Removal," Dec 2023, https://roads2removal.org/

Alongside the larger national goal of rapidly reducing current greenhouse gas emissions (GHG), CDR provides a vital option for achieving net-zero emissions by 2050.

The Roads to Removal report assesses key factors and pathways for physically removing CO_2 from the air at the scale of gigatonnes (billion-tonne) per year and then storing it away from the atmosphere through either ecological or geological means. This gigatonne CO_2-removal target is the climate clean-up needed in addition to dramatic reductions of emissions of greenhouse gases (GHGs) if the United States is to reach net-zero carbon emissions by or before 2050. In this report, sixty-eight authors examine (1) forestry, (2) cropland soils, (3) biomass (such as agricultural waste or municipal trash), (4) direct air capture (machines that remove CO_2 from the air), (5) transportation, (6) available zero-carbon energy, (7) geologic storage, and (8) environmental and socio-economic impacts. What you will read here integrates published data with original research on the major elements of negative emissions. Our granular analysis, with county-level resolution, shows that it is feasible for the United States to accomplish the carbon drawdown needed for net-zero emissions by the year 2050.

The focus and scope of this report is unique. We chose to only address practices and technologies that remove CO_2 from the air. We cover a breadth of strategies where we could make reliable estimates of what their application will require, ranging from land management to the latest technological options. We evaluate the costs for every step of the solution, from collection to transport to CO_2 storage. Our methods are intended to be transparent—we included details of our calculations in the body of this report and the appendices, and the underlying data are available at the report website.[1]

We purposefully chose to avoid discussing policies or current incentives. Rather, Roads to Removal provides a range of options, tradeoffs, and costs, aiming to enable informed decision-making in every community, region, and state in our country. Specifically, our goal is to give decision-makers the lens to see options clearly and make choices that will keep us all safer in the places we call home.

2. Roads to Removal – Executive Summary

I will mainly extract key findings from the R2R Executive Summary, and then will provide a brief summary of each carbon removal methods from the main chapters of this report. Note that I removed the secondary references from the extracted text for clarity.

Our analysis shows it is feasible for the United States to remove a staggering amount of CO_2 from the air—this will be critical to becoming carbon neutral by 2050. Our comprehensive, first-of-its-kind, county-resolution analysis indicates that our country can accomplish this goal by relying on demonstrated technology, natural resources, and workforces we already have. Additionally, ongoing technology development can lower costs, shorten timelines, and deliver new solutions. Our analysis evaluated how we can use forests, cropland soils, and waste biomass, along with purpose-built machines, to get us to net-zero. Further, we considered community impacts and identified locations where certain solutions could be uniquely beneficial or potentially counterproductive. Our findings enable decisionmakers to weigh both opportunities and constraints and to decide what roads to use to meet our national climate goal for net-zero CO_2 emissions.

The US strategy for achieving net-zero and eliminating ongoing, climate warming pollution has many possible pathways. We scaled our report's summary presentations to one gigatonne (1000 million tonnes) to be consistent with the 2021 Biden Administration Carbon Negative Earthshot goal of removing and storing CO_2 at the gigatonne-per-year scale…

The total amount of CO_2 removal the United States ultimately needs will depend on the success of policy and technology choices. Since the United States may decide to clean up larger amounts of CO_2 to compensate for historical pollution, this report also outlines ways to attain higher removal levels.

This report focuses on location-specific opportunities for removing and storing CO_2 in all 3143 counties in the United States. We examined these opportunities in the context of resource constraints and energy equity and environmental justice (EEEJ) considerations. Alongside the urgent and much larger national goal of rapidly cutting current greenhouse gas (GHG) emissions, CO_2 removal is required for the United States to achieve its net-zero emissions goals, meet international obligations, and help constrain global climate impacts.

Achieving the net-zero target will require the nation to hit both cost and volume goals for CO2 removal, while also meeting the needs of individual communities, states, and regions to avoid conflict with other critical priorities. This report evaluates CO_2-removal options with sufficient detail to inform these important decisions. Our analysis enables counties and CO_2-removal practitioners to work together to decide where, when, and how much of each approach fits into their local needs and what contribution each county can make to the national effort to eliminate CO_2 pollution.

We chose to evaluate CO_2-removal options from five sectors which are mature enough today to allow reasonable estimates of that approach's specific needs and its future costs. We assessed data for forestry, cropland soils, biomass carbon removal and storage (BiCRS), direct air capture with storage (DACS), and geologic storage (Figure ES-2) with county-level geographic resolution (where possible) …

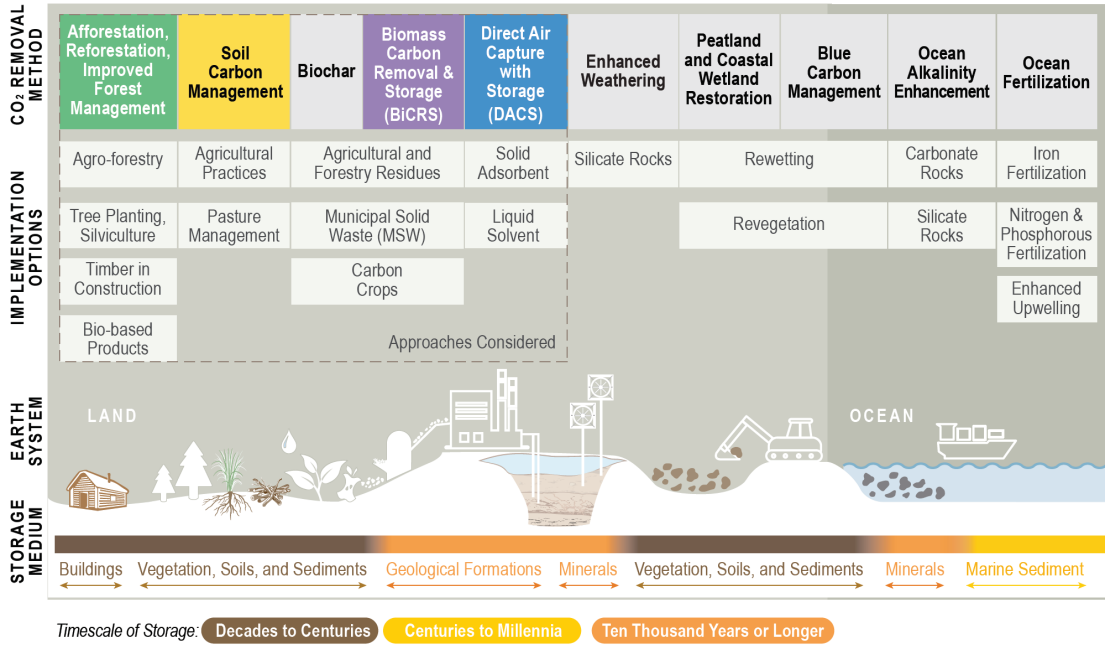

Figure ES-2. *Conceptual illustration of options available for CO_2 removal, redrawn from Figure 2 in Minx et al. 2018[2]. CO_2 removal methods analyzed in this report are highlighted in color. We considered only CO_2-removal strategies with sufficient county-level resolution information (circa 2022) to estimate costs and established an inclusion threshold of at least 10 million tonnes of CO_2 removal per year for a CO_2-removal strategy to be considered.*

[2] Jan C. Minx et al., Negative emissions—Part 1: Research landscape and synthesis, 2018. Environmental Research Letters 13(6): p. 063001, https://iopscience.iop.org/article/10.1088/1748-9326/aabf9b/meta

3. Forest Management for Carbon Removal

In this chapter, we adopt this framing and consider that new forest-management activities that lead to net atmospheric reductions in CO_2 are viable CO_2-removal pathways. Forest management is a well-studied road to removal with strong scientific underpinnings and an experienced knowledge base of foresters to implement management practices.

Growing evidence indicates that "climate-smart" forest-management practices may increase forest-carbon durability and reduce forest emissions. Additionally, forest management has benefits beyond CO_2 removal and storage. Forests are vital for wildlife and biodiversity; they provide food, fuel, timber, and fiber to society; they clean our air and water; and they are of immense cultural, aesthetic, recreational, and spiritual value.

The variety and importance of the suite of services forests provide creates numerous opportunities, but also numerous challenges, for managing the Nation's forests. Forest management for singular purposes will nearly always lead to tradeoffs among forest services; for this reason, the US Department of Agriculture (USDA) recognizes that there is no singular one-size-fits-all climate-smart forest strategy to pursue across the Nation's forests. Instead, forest-management strategies should be place-based, flexible, and locally led and account for the other forest benefits or potential adverse impacts.

Following this ethos, we present three case studies that represent region-specific examples of forest management for carbon removal and storage that are place based and climate-smart. We selected management options that are tailored to regional land-use legacies and strengths of current timber markets, are likely to make forests more resilient to future unpredictable weather and climate events, and are geared toward increasing carbon-removal capacity and the durability of stored carbon.

Policymakers or forest managers have three primary levers they can pull to increase forest carbon: (1) increasing the total forestland area of the Nation, (2) increasing the rate at which forests remove CO_2 from the atmosphere, and (3) increasing the durability of forest-carbon storage. Importantly, forest management practices can pull multiple levers simultaneously while also positively influencing other forest services. In this chapter, we review and build from the extensive knowledge of forestland management for CO_2 removal and demonstrate through three case studies how regionally specific forest-management practices provide viable roads to removal. We find through these three case studies the total forest CO_2-removal potential is between 1.5 and 1.8 billion tonnes of CO_2 equivalent (CO_2e) by 2050.

Prior research has consistently shown that increasing the Nation's total forestland through tree planting is an efficient and scalable CO_2-removal option. Multiple national studies estimate newly planted trees could annually remove between 27.6 and 314.2 million metric tonnes of CO_2e, with many identifying the southeastern United States as a region of opportunity. The wide variation in CO_2-removal estimates emphasizes the challenges in projecting the impact of forest-management actions across such an ecologically and economically diverse Nation…

Wildfire is the leading cause of forest emissions for the Nation's forests today. From 2017–2021, wildfires emitted an average of 140.8 million tonnes of CO_2 annually, and forests in six western states are now net carbon sources. There is widespread agreement that implementing "fire-smart" management in dry western forests may be one of the most important practices for protecting the durability of their carbon stocks and may increase the rate at which these forests remove CO_2…

The current health and condition of the Nation's forests today directly stem from historical management decisions. Adopting regionally appropriate silvicultural practices can potentially increase the rate at which forests remove CO_2 and increase the durability of forest-carbon stocks from large losses after natural disturbances, as well as maintain supplies of wood products and potentially provide economic incentives to prevent the sale of forestlands for development…

3.1. Biden Administration Makes a Major Move

The Biden-Harris Administration is today taking new and historic steps to implement President Biden's direction – issued in his Earth Day 2022 Executive Order on Strengthening the Nation's Forests, Communities, and Local Economies – to conserve and restore America's mature and old growth forests. America's forests are a key climate solution, absorbing carbon dioxide equivalent to more than 10% of U.S. annual greenhouse gas emissions. President Biden is leading and delivering on the most ambitious climate agenda in history, including by already protecting more than 26 million acres of lands and waters, and today's actions will build on this historic progress.[3]

Old and mature forests are vital to providing clean water, absorbing carbon pollution, and supplying habitat for wildlife. ***Today's actions include a first-of-its kind proposal from the U.S. Department of Agriculture (USDA) to amend all 128 forest land management plans across the country to conserve and restore old-growth forests across the National Forest System.*** *This will provide consistent direction across the Forest Service on how to conserve and restore old-growth forest conditions across the nation, and marks the first time that the Forest Service has adopted a nationwide forest plan amendment to guide new management direction on all national forests at once…*

Back to Reference 1.

4. CO_2 Removal and Storage in US Cropland Soils

Increasing organic carbon stocks in cropland soils is a prime target for near-term, soil-based CO_2 removal because croplands are already heavily managed and cover a large expanse of the United States. In addition, practices that enhance organic carbon in croplands are established, low-energy, and immediately deployable with many co-benefits. Our analysis examined the coupled economic and technical potential for cropland soil-based CO_2 removal at a county-level across the contiguous United States. We analyzed spatially explicit responses of cropland organic carbon and greenhouse gas (GHG) emissions to a suite of management practices (cover crops, perennial field borders, and perennial carbon crops), from 2025 through the year 2050 using the DayCent and SALUS biogeochemical models. We used soil organic carbon (SOC) changes and GHG emissions as inputs in an economic land-use decision model across a range of incentives for climate-change mitigation to explore sensitivity to a future carbon price. We deconflicted and prioritized land use to avoid double-counting and summed additive practices to quantify local, regional, and national potential for soil-based CO_2 removal. Here, we consider key uncertainties such as durability and measurability, discuss environmental and social co-benefits of each practice, and note important equity considerations with the financial valuation of soil-based CO_2 removal.

[3] White House Briefing Room, "FACT SHEET: Biden-Harris Administration Advances Commitment to Protect Old Growth Forests on National Forest System Lands," Dec 19, 2023, https://www.whitehouse.gov/briefing-room/statements-releases/2023/12/19/fact-sheet-biden-harris-administration-advances-commitment-to-protect-old-growth-forests-on-national-forest-system-lands/?et_rid=17039174&et_cid=5056286

Key Findings:

Soil-based CO_2 removal and storage is one of many benefits of cropland-management practices designed to reduce soil erosion, reduce nitrous oxide (N_2O) emissions, improve water retention, and provide bird and other wildlife habitat.

Cropland-management practices, including cover crops (unharvested vegetation planted on otherwise fallow fields), perennial field borders (trees or native grasses planted along edges of a cropped field), and perennial carbon crops (planting native perennial grasses to harvest and sell to a carbon biomass market) remove atmospheric CO_2 through increased photosynthesis and subsequent storage of a portion of newly photosynthesized carbon in roots and SOC.

Soil-based CO_2 storage in croplands is a low-energy, immediately deployable strategy that could economically remove a cumulative 130 million tonnes of CO_2 between 2025 and 2050 if farmers were offered a moderate price of $40/tonne CO_2 equivalent (CO2e).

Hotspots of opportunity for cropland soil-based CO_2 removal are the Lower Great Lakes, Southeast, and Lower Mississippi River regions, with cover cropping composing more than 75% of cumulative profitable CO_2 removal between 2025 and 2050.

Durability of soil-based CO_2 storage is highly uncertain, and cropland soil management should be considered a near-term component to a national strategy that eventually transitions the equivalent CO_2 storage to highly durable geologic storage.

To avoid exacerbating existing extreme inequalities in land ownership, an equitable cropland soil-based CO_2-removal incentive program must carefully consider to whom funds will flow.