FOUNDATION FOR CLIMATE RESTORATION

CLIMATE RESTORATION:

ACHIEVING A SAFE AND HEALTHY CLIMATE BY 2050

FEBRUARY 2022

"Far from being a quick or easy 'fix,' climate restoration is an idea that is not just technologically optimistic, but also radically socially optimistic, for it implies that we could chart our way through this mess and reconstitute a climate that is safe for people to grow regenerative food and live healthy lives."[1]

—Dr. Holly Jean Buck

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WHY DO WE NEED CLIMATE RESTORATION?

The long-term survival of humans and ecosystems requires a climate similar to the one in which we have evolved and flourished. However, the trillion tons of legacy carbon dioxide in our atmosphere, which have accumulated since the Industrial Revolution, have put a climate in which we can all thrive increasingly out of reach.[2]

CLIMATE-RELATED DISASTERS ARE GROWING MORE FREQUENT AS OUR PLANET WARMS

The scientific community has been documenting the devastating impacts of climate change and has noted an increase in heat waves, fires, floods, droughts, crop failures, the destruction of our coral reefs and other ecosystems, massive extinctions of various species, and the spread of new diseases in the last decade. In addition to the more visible effects of climate change, the warming of our planet also threatens our long-term health outcomes, our economic prospects, and our international security,[3] with marginalized populations bearing a disproportionate burden.[4]

Indigenous coastal communities and Small Island Developing States are particularly threatened by intensifying tropical storms, rising sea levels, and the ocean acidification caused by a warmer planet.[5] Already hot areas of the globe will see an increase in heat waves and related health conditions, like heat exhaustion and heat stroke.[6] Low-income populations, which are more likely to live in rural areas and rely on agriculture for their livelihood, are at greater risk of food and water insecurity, decreased agricultural productivity, and disease outbreaks.[7] Black, Indigenous, and other communities of color are more likely to live near industrial facilities and in areas with heavy pollution and thus face a higher risk of chemical spills and toxic leaks resulting from extreme weather events.[8] And it is the same communities most impacted by global warming that lack the infrastructure and resources to respond to these climate-related disasters.[9]

Climate change, whether through extreme weather conditions, changed patterns of disease, or reduced agricultural production, already causes over 150,000 deaths annually.[10] With global temperatures expected to increase at least 1.5°C by the end of the century, intervention is imperative, and we must address the main driver of global warming: legacy CO_2. If deployed thoughtfully, the removal of this legacy CO_2 using carbon dioxide removal (CDR) methods has the potential to address the aforementioned impacts and burdens while prioritizing justice and equity within its deployment.

[1] Buck, H.J. (2019). *After Geoengineering: Climate tragedy, repair, and restoration.* Verso: London.

[2] Friedmann, S. J. (2019, July 26). Engineered CO_2 Removal, Climate Restoration, and Humility. *Frontiers in Climate*, 1. Retrieved January 22, 2022, from https://www.frontiersin.org/articles/10.3389/fclim.2019.00003/full

[3] Permanent Mission of Germany to the United Nations. (2020, 07 24). *Joint statement by 10 members of the United Nations Security Council (Belgium, the Dominican Republic, Estonia, France, Germany, Niger, Tunisia, St. Vincent and the Grenadines, the United Kingdom, Viet Nam) and 3 incoming members of the United Nations Sec*. https://new-york-un.diplo.de/un-en/news-corner/200724-climate/2368770

[4] EPA. (2021, 07). *Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts*. United States Environmental Protection Agency, EPA 430-R-21-003. https://www.epa.gov/cira/social-vulnerability-report

[5] EPA. (2021). *Ocean Acidification: Effects of Ocean and Coastal Acidification on Ecosystems*. United States Environmental Protection Agency. https://www.epa.gov/ocean-acidification/effects-ocean-and-coastal-acidification-ecosystems

[6] EPA. (2021, 07). *Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts*. United States Environmental Protection Agency, EPA 430-R-21-003. https://www.epa.gov/cira/social-vulnerability-report

[7] U.S Global Leadership Coalition. (2021, 03). *Climate Change and the Developing World: A Disproportionate Impact.* U.S Global Leadership Coalition. Retrieved January 22, 2022, from https://www.usglc.org/blog/climate-change-and-the-developing-world-a-disproportionate-impact/

THE EXCESS CARBON IN OUR ATMOSPHERE IS THE MAIN DRIVER OF CLIMATE CHANGE

We began to burn fossil fuels over two hundred years ago, at the beginning of the Industrial Revolution. At that point, atmospheric CO_2 was an estimated 270 parts per million. As our world has industrialized, we have continued to emit massive amounts of carbon, and today, there are nearly a trillion tons of excess carbon in our atmosphere. This "legacy carbon" has increased our atmospheric CO_2 levels to 419 ppm.[12]

Without intervention, atmospheric CO_2 will grow to 450 ppm in 2050.[13] This level of CO_2 is 50% higher than human beings have ever survived long-term and is responsible for the climate change we are seeing today.[14] While there are other greenhouse gases (GHGs) that contribute to our changing climate, CO_2 is the largest contributor with the longest atmospheric lifespan.

WHAT ABOUT OTHER GHGS?

METHANE[15]

Methane has at least 84 times the GHG potency of carbon dioxide over a span of 20 years,[16] and atmospheric methane levels are rising rapidly. While methane has a short half-life in the atmosphere (approximately 9.1 years), emissions are rising so fast that atmospheric methane is at double the preindustrial levels. Stopping human-driven methane emissions is critical and will help reduce atmospheric methane concentrations, but, like CO_2 emissions reductions, even this won't get atmospheric methane down to safe levels. For that, methane must also be removed from the atmosphere. Research into atmospheric methane removal is underway, but more work is needed.

HYDROFLUOROCARBONS (HCFS)[17]

HFCs are a group of incredibly potent GHGs with global warming potential thousands of times higher than carbon dioxide. They are commonly used in refrigeration, air conditioning, building insulation, and more. Their atmospheric lifetimes range from a few days to several hundred years.[18] While they are currently responsible for only a small portion of emissions, HFCs are the fastest-growing class of GHG, and demand for them is expected to continue rising as the global climate warms. Climate-friendly alternatives to HCFs exist, and countries around the world are beginning to place restrictions on HCF usage to accelerate the transition to safer options.

[8] EPA. (2021, 07). *Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts.* United States Environmental Protection Agency, EPA 430-R-21-003. https://www.epa.gov/cira/social-vulnerability-report

[9] Islam, S. N., & Winkel, J. (2017, 10). *Climate Change and Social Inequality* (N° 152 ed.). United Nations - Department of Economic & Social Affairs. https://www.un.org/esa/desa/papers/2017/wp152_2017.pdf

[10] The Health and Environment Linkages Initiative. (2021). *Priority environment and health risks: Climate change.* Health and Environment Linkages Initiative - HELI. https://www.who.int/heli/risks/climate/climatechange/en/

[11] Friedmann, S. J. (2019, July 26). Engineered CO_2 Removal, Climate Restoration, and Humility. *Frontiers in Climate*, 1. Retrieved January 22, 2022, from https://www.frontiersin.org/articles/10.3389/fclim.2019.00003/full

[12] Mcdaniel, E. (2021, 06 07). *Carbon Dioxide, Which Drives Climate Change, Reaches Highest Level In 4 Million Years*. NPR. Retrieved January 22, 2022, from https://www.npr.org/2021/06/07/1004097672/atmospheric-carbon-dioxide-fueling-climate-change-hits-a-four-million-year-high

MITIGATION AND ADAPTATION ALONE CANNOT ADDRESS OUR RAPIDLY WARMING CLIMATE

The global community has made significant strides in both mitigation[19] and adaptation[20] by working to cut carbon emissions and respond resourcefully to a warming climate. However, mitigation efforts, like the reduction of carbon emissions, address only 5% of the problem: it is the trillion tons of excess CO_2 *already* in our atmosphere, not just present-day emissions, that drive global warming.[21] Therefore, even if we were to achieve net-zero emissions, we would still be faced with the grim impacts of climate change.

At the Foundation for Climate Restoration (F4CR), we think of this problem as an overflowing bathtub. We must "turn off the tap" by dramatically reducing carbon emissions and working urgently towards a net-zero future. But, if we want to reverse global warming, we must also remove the "flood" of carbon that has been accumulating in our atmosphere since the Industrial Revolution. This is the only way to restore our climate to safe levels of atmospheric carbon.

In light of this, the emerging field of climate restoration has set an ambitious goal: ensure the survival of humanity by restoring atmospheric CO_2 to safe, pre-industrial levels by 2050. This must be done in conjunction with mitigation and adaptation: we cannot avoid the hard work of decarbonizing our economy, transitioning to clean energy, and adapting to warming-related phenomena like rising sea levels. We must commit to implementing mitigation, adaptation, and climate restoration in concert and with urgency.

CLIMATE RESTORATION CANNOT WAIT

Some suggest that we should end present-day emissions before we work to remove historic emissions. It is true that climate restoration without emissions reduction would be futile: in effect, we would be opening the drain in our metaphorical bathtub while keeping the faucet on full blast. Additionally, if we don't remain committed to achieving net-zero emissions, then we will only prolong the life of the fossil fuel industry, whose detrimental impact on our environment is well-documented.[22]

But climate restoration cannot wait. If we begin to invest in both natural and technological solutions only once we are at net-zero emissions, it will be too late. The research, testing, investment, innovation, governance, and policy mechanisms needed for gigaton-scale CDR will take time to implement. Expanding and optimizing the drain for our tub will not happen overnight.

When it comes to risk management of the climate crisis, it is critical to pursue a diverse range of options. It takes time to coordinate the many moving parts associated with CDR solutions, including scalable land management, carbon markets, and the research and development needed to reduce risks of any potential negative impacts. Time and effort is needed now to coordinate collective global action. Because legacy carbon is the main driver of global warming, we will continue to see climate change impacts *even if* we rapidly and dramatically reduce emissions.[23] It is not until we also address the trillion tons of historic emissions in our atmosphere that we can move the needle on global warming. If we want to reverse climate change, then we must make mitigation *and* restoration our top priorities.

WHAT IS CLIMATE RESTORATION?

"Rapidly stopping emissions is critical. But so much carbon dioxide is already above us that emissions cuts alone are no longer enough to keep warming to safe levels: the weight of past CO_2 also needs to be dealt with. At the same time that we are cutting that 50 Gt of greenhouse gases to zero, we also need to be building the capacity to remove hundreds of billions of additional tons from the atmosphere."[24]

—Dr. Holly Jean Buck

Climate restoration is the safe and permanent removal of excess CO_2 so that our climate is returned to pre-industrial levels of atmospheric carbon. We know that humanity and the natural world thrived in the climate we had before the Industrial Revolution, when CO_2 was below 300 ppm. Therefore, the explicit aim of the Foundation is to reduce atmospheric CO_2 from today's levels of over 415 ppm to below 300 ppm by 2050.

Lowering atmospheric carbon by 115 ppm will require sequestering about one trillion tons of carbon dioxide. The task—safely capturing a trillion tons of CO_2 from the air and storing it for hundreds to thousands of years—sounds enormous. And it is. But promising solutions and financing strategies already exist.

Historically, climate action has not been driven by a coherent goal and has instead been oriented toward narrowly avoiding catastrophic outcomes. To date, the field of climate science has focused on predicting, describing, and explaining climate change and then modeling what would happen if we changed "x" or "y." For example, the Paris Agreement has set a target of no more than a 1.5°C increase in global temperature.[25] Because this target was negotiated based on economic feasibility, rather than with the explicit intention of creating a livable climate, we are left without a desirable—or arguably, survivable—outcome for global climate action.

Climate restoration has shifted the climate action paradigm by committing to the ambitious but feasible goal of reducing carbon levels by 115 ppm by 2050. This new paradigm aligns research, policy, and plans with the outcome we actually want: a climate in which humanity and the natural world can thrive.

[13] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

[14] Jones, N. (2017, January 26). *How the World Passed a Carbon Threshold and Why It Matters.* Yale E360. Retrieved January 22, 2022, from https://e360.yale.edu/features/how-the-world-passed-a-carbon-threshold-400ppm-and-why-it-matters

[15] Methane Action. (n.d.). *About Methane Action*. Methane Action. Retrieved February 2, 2022, from https://methaneaction.org/about/

[16] Intergovernmental Panel on Climate Change. (2014). Myhre, G., D. et al. (Eds). Anthropogenic and Natural Radiative Forcing. In Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 659-740). Cambridge: Cambridge University Press. doi:10.1017/CBO9781107415324.018.

[17] NRDC. (2017) Climate Action: Global transition away from HFCs. https://www.nrdc.org/experts/anjali-jaiswal/climate-action-global-transition-away-hfcs-moving-forw

[18] EFCTC. (2020) Major HFC, HFO and HCFOs; HCFC molecules used as feedstocks. https://www.fluorocarbons.org/wp-content/uploads/2020/07/2020_07_27_Fluorocarbon-Molecules-environmental-properties-and-main-applications-2020-July.pdf

[19] Mitigation refers to the implementation of policies, regulations, and standards that lower levels of carbon emissions.

[20] Adaptation refers to how we alter our behavior in order to survive in a rapidly warming climate.

[21] Lindsey, R. (2020, 08 14). *Climate Change: Atmospheric Carbon Dioxide*. NOAA Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

[22] EESI. (2021, 07 22). *Fossil Fuels.* Environmental and Energy Study Institute. https://www.eesi.org/topics/fossil-fuels/description

[23] Bergman, A., & Rinberg, A. (2021). Harms and co-benefits of large-scale CDR deployment. *In CDR Primer*. J Wilcox, B Kolosz, & J Freeman. https://cdrprimer.org/read/chapter-1#sec-1-6

HOW IS CLIMATE RESTORATION DIFFERENT FROM CARBON DIOXIDE REMOVAL?

When people first learn about climate restoration, they often conflate restoration with carbon dioxide removal (CDR). We want to be clear that climate restoration is an explicit goal, while CDR is a pathway to achieving that goal.

CDR is the removal of carbon dioxide from the atmosphere. CDR is different from carbon capture, which traps CO_2 at a point source, like a smokestack. CO_2 from both CDR and carbon capture can be used in a multitude of ways, including for synthetic jet fuel and soda carbonation. These terms simply refer to where the CO_2 is coming from and not necessarily where it is going.[26]

The success of climate restoration will depend heavily on the use of CDR, some carbon capture, and successful mitigation of our global emissions.

THE FOUR CRITERIA FOR CLIMATE RESTORATION SOLUTIONS

In the last few years, we have made significant progress in standardizing carbon dioxide removal requirements. For example, scholars have outlined the five Oxford Principles for Net Zero Aligned Carbon Offsetting,[27] and the XPRIZE Carbon Removal Competition has designed specific guidelines for durability, scalability, and cost-effectiveness.[28]

These standardized carbon removal requirements differ from ours to some degree due to the sheer size of our goal. Because climate restoration seeks to remove 50 Gt—or 50 billion tons—of CO_2 from the atmosphere per year, a restorative solution must be able to store CO_2 for over 100 years, must be scalable to at least 10 Gt per year, must be financeable with existing or easily mobilized funds, and must be equitable, which means the solution can be developed and deployed in a way that fairly distributes the benefits and burdens to all, regardless of income, race, and other characteristics.[29]

THE SOLUTION MUST BE PERMANENT

“Permanent” means that the captured CO_2 stays securely out of circulation for at least a century. Mineralization, for example, is permanent because the CO_2 stays locked up in the rock unless heated by a volcanic eruption or baked in a kiln.

[24] Buck, H. J. (2020, June 22). *Holly Jean Buck: How to Decolonize the Atmosphere.* Progressive International. Retrieved January 22, 2022, from https://progressive.international/blueprint/46253391-5b3d-4e68-bd3f-d53dc54180fd-holly-jean-buck-how-to-decolonize-the-atmosphere/en

[25] United Nations. (n.d.). *The Paris Agreement.* UNFCCC. Retrieved January 22, 2022, from https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[26] Freedman, A. (2013, 05 3). *The Last Time CO_2 Was This High, Humans Didn't Exist.* Climate Central. https://www.climatecentral.org/news/the-last-time-co2-was-this-high-humans-didnt-exist-15938

[27] Allen, M., Axelsson, K., Caldecott, B., Hale, T., Hepburn, C., Hickey, C., Mitchell-Larson, E., Malhi, Y., Otto, F., Seddon, N., & Smith, S. (2020). *The Oxford Principles for Net Zero Aligned Carbon Offsetting*. The Smith School of Enterprise and the Environment. https://www.smithschool.ox.ac.uk/publications/reports/Oxford-Offsetting-Principles-2020.pdf

[28] XPRIZE Foundation. (2021). *XPRIZE Carbon Removal Competition Guidelines.* https://assets-us-01.kc-usercontent.com/5cb25086-82d2-4c89-94f0-8450813a0fd3/c2e7fad6-ff36-4c70-a665-91b27823e451/XPRIZE%20CARBON%20REMOVAL%20GUIDELINES.pdf

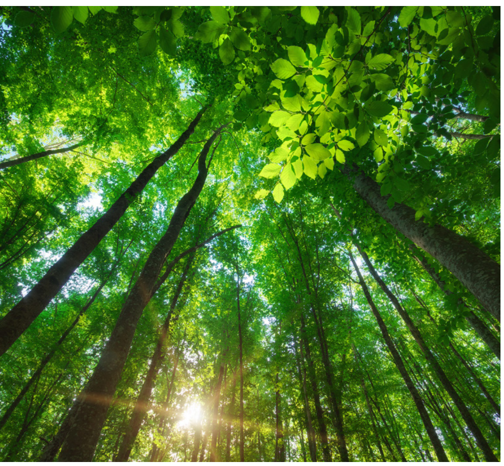
[29] It bears noting that a method must first be safe in order to be viable. For any climate restoration method, intensive testing, monitoring, course correction, and continuous improvement are required to ensure the solution's safety.

There are some proposed methods that are not permanent and therefore not restorative: carbonated drinks made with captured CO_2, carbon-neutral fuels that may replace fossil fuels but do not sequester CO_2, and enhanced oil recovery, which uses carbon-capture for the purpose of extracting more fossil fuels. While these uses do recycle CO_2, they do not help reduce atmospheric CO_2.

Over the last couple years, most CDR organizations have raised the bar for what qualifies as durable carbon storage to a century or more, so our standard for permanence is roughly the same.

THE SOLUTION MUST BE SCALABLE

"Scalable" means that the solution can be scaled up within a decade to remove and store at least 10 Gt of CO_2 per year. We could therefore withdraw 50 Gt of CO_2 per year by scaling only a small handful of methods. Mineralization and ocean restoration are very promising in this respect because the markets for their commercial byproducts (e.g., rock, seaweed, and seafood) are large enough to take in half or more of the excess CO_2 from our atmosphere each year.



One commonly proposed method, bioenergy with carbon capture and storage (BECCS), is less likely to meet the scalability requirement for climate restoration. This is because BECCS would require more land than is currently available to remove and store at least 10 Gt of carbon per year. To scale BECCS further would use land needed for forests or food production.[30]

At 10 Gt per year,[31] our requirement for scalability is considerably higher than most. However, the development of solutions has recently accelerated thanks in part to the Carbon Removal XPRIZE competition, the increasing demand for and availability of carbon removal credits, and some initial public financing for carbon removal in the US. With a growing number of solutions ready for implementation or in development, the total burden of 50 Gt of CO_2 removal per year can be distributed across a greater number of solutions and companies.

THE SOLUTION MUST BE FINANCEABLE

"Financeable" means that funding is already available or can be mobilized. A method is financeable when it produces something that can satisfy a large and existing market, such as that for construction materials[32] or seafood.[33] A method might also be financially feasible if it has a low cost for each ton of CO_2 captured and stored. For example, carbon storage in construction materials could easily be funded by the consumers of those materials given that there is existing demand. Similarly, farmed products grown on soil fortified with biochar may also qualify as financeable because the revenue from agricultural products could more than make up for the cost of using biochar to lock the CO_2 into the soil.[34]

[30] Belmont, E., Jacobson, R., & Sanchez, D. L. (2021). Biomass energy with carbon capture and storage (BECCS). In *CDR Primer*. J Wilcox, B Kolosz, & J Freeman. https://cdrprimer.org/read/chapter-2#sec-2-7

[31] It is worth mentioning that our previous standard for scalability was 25 Gt/year. We have since revised this figure because the number of CDR solutions now available make the more ambitious goal of 50 Gt/year feasible.

[32] Global Industry Analysts, Inc. (2021). *Construction Materials - Global Market Trajectory & Analytics.* Retrieved January 22, 2022, from https://www.researchandmarkets.com/reports/338354/construction_materials_global_market_trajectory

[33] Shahbandeh, M. (2020, 10 5). *Global seafood market value 2019-2027.* Statista. https://www.statista.com/statistics/821023/global-seafood-market-value/

Methods that are not as easily financed include those without existing, sufficiently-sized markets, like geologic storage of CO_2. Some amount of geologic storage will certainly be needed for a portion of our excess CO_2, but its implementation would require either public financing or voluntary private financing.[35] The voluntary carbon removal market has grown dramatically over the past couple years, but it is unlikely to generate enough revenue to pay for the geologic storage of at least 10 Gt of CO_2 per year due to its cost (i.e., over $1.5 trillion per year).[36]

The climate restoration standard for financeability puts more focus on consumer markets, rather than on public funding, so the size of the market and the value of the resulting commercial goods are especially important.[37] With Microsoft's commitment to becoming carbon negative by 2030[38] and other companies following suit (e.g., Stripe and Shopify),[39] demand for carbon removal has outstripped supply.[40] There are now millions of dollars of private capital that have been made available for carbon removal with no commercial byproducts required.[41] This increase in private capital for large-scale CDR has created a seller's market: those working on durable CDR solutions can name their price for the carbon removal credits they have to sell. This gives innovators more flexibility to scale new CDR pathways than we would have expected even a year ago. Still, it is hard to predict how large this market will grow or how long it will last.

THE SOLUTION MUST BE EQUITABLE

"Equitable" means that the solution considers benefits and risks to all communities, specifically vulnerable and oppressed groups. Climate change is a universal threat that is felt earliest and hardest by those individuals with the fewest resources to confront the crises it generates.

Equitable deployment of restorative solutions will need to consider procedural justice (i.e., fair decision-making processes), distributive justice (i.e., fair allocation of benefits), reparative justice (i.e., amends for previous harm), and transformative justice (i.e., addressing structural power imbalances), especially for frontline communities and stakeholders.[42]

With the addition of this fourth pillar, which we will more fully explore in our upcoming Solution Series, we commit to researching, understanding, and advocating for equitable outcomes in our work to restore the climate.

[34] Belmont, E., Torn, M., Sanchez, D. L., & Smith, P. (2021). Biochar. In *CDR Primer*. Wilcox, J; Kolosz, B; Freeman, J. https://cdrprimer.org/read/chapter-2#sec-2-6

[35] Honegger, M., Poralla, M., Michaelowa, A., & Ahonen, H.-M. (2021). Who Is Paying for Carbon Dioxide Removal? Designing Policy Instruments for Mobilizing Negative Emissions Technologies. *Frontiers in Climate*, 3. 10.3389/fclim.2021.672996

[36] Upton, J., & Zimmerman, J. (2013, June 28). *Centuries worth of CO_2 emissions could be stored underground, but at what cost?* Grist. Retrieved January 23, 2022, from https://grist.org/climate-energy/centuries-worth-of-co2-emissions-could-be-stored-underground-but-at-what-cost/

[37] Friedmann, S. J. (2019, July 26). Engineered CO_2 Removal, Climate Restoration, and Humility. Frontiers in Climate, 1. Retrieved January 22, 2022, from https://www.frontiersin.org/articles/10.3389/fclim.2019.00003/full

[38] United Nations. (n.d.). *Microsoft: Carbon Negative Goal | Global.* UNFCCC. Retrieved January 23, 2022, from https://unfccc.int/climate-action/un-global-climate-action-awards/climate-neutral-now/microsoft-carbon-negative-goal

[39] Bullard, N. (2021, June 3). *Stripe, Shopify, and the E-Commerce Approach to Drawing Down Carbon.* Bloomberg.com. Retrieved January 23, 2022, from https://www.bloomberg.com/news/articles/2021-06-03/stripe-shopify-and-the-e-commerce-approach-to-drawing-down-carbon

[40] Wilcox, M. (2021, August 9). *7 things to know about carbon removal markets | Greenbiz.* GreenBiz. Retrieved January 23, 2022, from https://www.greenbiz.com/article/7-things-know-about-carbon-removal-markets

HOW DO WE IMPLEMENT CLIMATE RESTORATION?

No single solution will restore our climate. Some approaches have the advantage of being more scalable, more cost-effective, or more co-beneficial than others. It will thus take a portfolio of solutions deployed in concert to achieve climate restoration's goal.

Some of the most promising solutions are methods that use "biomimicry" and "geomimicry" to copy the natural processes that significantly reduce CO_2 levels.[43] Biomimicry technologies replicate the same processes that have allowed the natural world to recover following mass extinction events in the past. For example, when atmospheric CO_2 has grown too high, it has been naturally sequestered into limestone and into underwater biocarbon stores in the ocean.[44]

In **Appendix I**, we provide a brief overview of CDR solutions and their trade-offs when viewed through a climate restoration lens. Several of these solutions are ready for implementation or in the process of implementation. More research is needed for many of them, and the most credible projections regarding their ability to scale are based on historic assumptions about economic viability. However, we have seen disruptive industries like solar energy benefit from government support[45] and scale far faster and to a greater extent than even the most optimistic models projected.[46] Given the importance of these restorative solutions, we are therefore optimistic that we will see similarly rapid and significant scaling here.

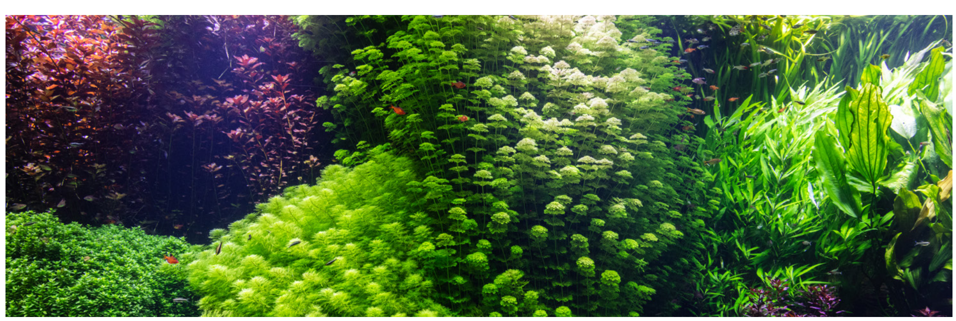
HOW CAN WE ACCELERATE AND SCALE CLIMATE RESTORATION?

"It's helpful to remember that the case for CDR is extremely compelling, founded in daunting and incontrovertible math and science. We do what we do first and foremost because it is necessary and because we value our progress, civilization, and the glory of the natural world. This is true regardless of how difficult the path or how vexing the societal circumstances of the undertaking. Cleaning our collective room may be unpleasant but is ultimately necessary and is the work of climate restoration."[47]

—Dr. S. Julio Friedmann

When people learn that we have climate restoration solutions already available, they often wonder why they are not yet implemented at scale. Simply put, we currently lack the political will and significant investment needed to accelerate their implementation.

As with any field requiring collective action, government policy has the greatest leverage to accelerate climate restoration. As Dr. Holly Jean Buck writes, "Climate-significant carbon removal infrastructure will take decades to construct, because it takes time to develop the technology, prove it, regulate it, finance it, [and] build it...It needs to be in the R&D stage now, with significant public funding."[48] With this in mind, we will outline below how individuals can support the implementation of climate restoration policies at all levels of government. These policies can also serve as a compass for the private sector (e.g., investors and venture capitalists) and for citizen-advocates and civil society groups who are looking to support the policy initiatives that will ensure we have a habitable planet for future generations.



POLICY OPPORTUNITIES TO FURTHER CLIMATE RESTORATION GOALS

"If you're like Joe Schmo, and you're looking to do something for the climate, I think you should give to policy…We think it's something like 10 times more effective to give to policy than to give to one of these projects that are directly doing emissions reductions."[49]

—Daniel Stein

PROCUREMENT POLICY THAT PRIORITIZES THE USE OF LOW-CARBON AND CARBON-NEGATIVE MATERIALS

Governments spend an enormous amount of money on construction materials like concrete. In fact, governments are the largest procurers of concrete in the world.[50] Therefore, shifting to policies and regulations that further climate restoration's goals (e.g., choosing to procure concrete that uses carbon-sequestering technology or directly procuring permanent carbon removal from direct air capture facilities) can have an outsized impact on an entire government's carbon footprint.

Concrete is the second-most consumed material after water,[51] so turning it from a net emitter responsible for 8% of annual global emissions[52] to a net carbon sink would allow us to permanently store billions of tons of carbon dioxide each year. To achieve this, government policies must explicitly consider the carbon footprint of the concrete used in infrastructure projects so that the lowest-carbon materials gain a market advantage.[53] Three important components of such policies include:

DISCLOSURE

Currently, there are no universal requirements for concrete producers to disclose the environmental impact of their products.[54] Determining the environmental impact of concrete can be expensive and time-consuming because it requires a detailed life cycle analysis and because of the wide variety of concrete mixes used (e.g., concrete for sidewalks versus concrete for skyscrapers).[55] These analyses can cost upwards of tens of thousands of dollars.

[41] While the millions of dollars available is still far short of the trillions needed for geologic storage, it is a step in the right direction.

[42] Kosar, U., & Suarez, V. (2021). Removing Forward: Centering Equity and Justice in a Carbon-Removing Future. Carbon 180. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/6115485ae47e7f00829083e1/1628784739915/Carbon180+RemovingForward.pdf

[43] Seckler, I. (2020, 01 10). *The Next Climate Tech Breakthrough May Have Already Happened, We Just Didn't Notice.* Columbia Climate School. https://news.climate.columbia.edu/2020/01/10/biomimicry-climate-sustainability/

[44] Dutkiewicz, A., Müller, D. R., Cannon, J., & Vaughan, S. (2018). Sequestration and subduction of deep-sea carbonate in the global ocean since the Early Cretaceous. Geology, 91-94. https://doi.org/10.1130/G45424.1

[45] Solar Energy Industries Association. (n.d.). *What rebates and incentives are available for solar energy?* | SEIA. Solar Energy Industries Association. Retrieved January 23, 2022, from https://www.seia.org/initiatives/what-rebates-and-incentives-are-available-solar-energy

[46] Davis, M., White, B., Goldstein, R., Leyba Martinez, S., Chopra, S., Gross, K., Sahd, M., Sun, X., Rumery, S., Silver, C., & Baca, J. (2021, December 14). *Solar Market Insight Report 2021 Q4 | SEIA.* Solar Energy Industries Association. Retrieved January 23, 2022, from https://www.seia.org/research-resources/solar-market-insight-report-2021-q4

[47] Friedmann, S. J. (2019, July 26). Engineered CO_2 Removal, Climate Restoration, and Humility. *Frontiers in Climate*, 1. Retrieved January 22, 2022, from https://www.frontiersin.org/articles/10.3389/fclim.2019.00003/full

[48] Buck, H. J. (2020, June 22). *Holly Jean Buck: How to Decolonize the Atmosphere.* Progressive International. Retrieved January 22, 2022, from https://progressive.international/blueprint/46253391-5b3d-4e68-bd3f-d53dc54180fd-holly-jean-buck-how-to-decolonize-the-atmosphere/en

[49] Meyer, R. (2021, December 15). *The Most Effective Nonprofits to Fight Climate Change.* The Atlantic. Retrieved January 23, 2022, from https://www.theatlantic.com/newsletters/archive/2021/12/most-effective-nonprofits-fight-climate-change/621013/

Fortunately, a new, more cost-effective measure of carbon-intensity of cementitious products has been introduced: CarbonStar®.[56] If widely adopted, CarbonStar would allow for faster reporting of a concrete's carbon footprint in a way that would make the comparison of different concrete products much easier. However, since CarbonStar is so new, it is not yet the industry standard and has not been widely adopted. CarbonStar is ideally suited for comparing the carbon-intensity of concrete products, but since it doesn't take into account the full life cycle of the products (e.g., emissions or other impacts from transportation or demolition), CarbonStar ratings could miss important characteristics of these products.

BENCHMARKING

Policymakers can set benchmarks to ensure that concrete products used in infrastructure projects meet some target of carbon intensity.[57] As low-carbon and carbon-negative concrete processes evolve, these benchmarks could become more ambitious. Eventually, concrete producers would be required to design mixes that could meet both the performance specifications of the project and the carbon intensity limits. They would then need to prioritize using techniques that reduce the carbon footprint of their products and ultimately reach a net-negative carbon footprint.

INCENTIVES

Even if a concrete producer chooses to disclose an Environmental Product Declaration (EPD),[58] governments generally lack the incentives to encourage the use of the most environmentally-friendly and low-carbon materials. Policy can be designed to put those incentive systems in place, either by requiring policymakers to take the EPD into account when selecting a bid for an infrastructure project or by providing a bonus to contractors after project completion if the products they use meet certain benchmarks for carbon intensity.

DIRECT GOVERNMENT PROCUREMENT OF CDR

In addition to implementing low-carbon and carbon-negative procurement policies, governments can also purchase carbon dioxide removal in the open market. Many government entities have net-zero targets that they could more easily meet if they used a small portion of their budgets to pay for CO_2 to be sequestered by CDR companies that could pull CO_2 from the air and then pump it underground to mineralize in geologic storage. This government investment would provide the capital needed for DAC to scale dramatically, increasing the supply of carbon removal credits available for the voluntary market and for the consumer and commercial products that use CO_2 as an input.

[50] Adams, M. P. (2021, June 23). *Concrete Solutions to Climate Change: How Local Policy Can Promote Sustainable Construction Activities*. Rockefeller Institute of Government. Retrieved January 23, 2022, from https://rockinst.org/issue-area/concrete-solutions-to-climate-change/

[51] Gagg, C. R. (2014). Cement and concrete as an engineering material: An historic appraisal and case study analysis. *Engineering Failure Analysis*, 40, 114-140. https://doi.org/10.1016/j.engfailanal.2014.02.004.

[52] Rodgers, L., & Huynh, L. (2018, December 17). *Climate change: The massive CO_2 emitter you may not know about.* BBC. Retrieved January 23, 2022, from https://www.bbc.com/news/science-environment-46455844

[53] Henrion, L., Zhang, D., Li, V., & Sick, V. (2021). Built Infrastructure Renewal and Climate Change Mitigation Can Both Find Solutions in CO_2. *Frontiers in Sustainability*, 2. DOI=10.3389/frsus.2021.733133 https://www.frontiersin.org/articles/10.3389/frsus.2021.733133/full

[54] Carbon Leadership Forum. (n.d.). *The Carbon Challenge.* Carbon Leadership Forum. Retrieved January 23, 2022, from https://carbonleadershipforum.org/the-carbon-challenge/

CARBON PRICING LEGISLATION TO ACCELERATE AND MAKE PREDICTABLE THE TRANSITION TO NET-ZERO

Many economists point out that climate change is essentially an economic issue: because it is free to put CO_2 into the air and costly to stop emitting, businesses make the logical business decision to continue emitting as usual. If we were to attach a fee to carbon emissions that increased at a steady, predictable rate, those same businesses would eventually reach a point at which it was no longer profitable to emit, and they would instead invest in capital improvements that get them near or to net-zero emissions. This type of policy could have a substantial impact on reducing emissions, and proceeds from the fees could be invested in the development and deployment of climate restoration solutions. However, despite past bipartisan support for a federal carbon fee and dividend bill in both the House and the Senate, this type of legislation has not yet been adopted in the United States.[59] Still, public support for carbon pricing is growing. Nearly three-quarters of Americans support taxing corporations for their emissions. More than 45 countries already price carbon. More than 3500 economists, including 28 Nobel laureates and 75% of Republicans under 40 years old support carbon pricing.[60]

INVESTMENT TAX CREDITS

History has shown that, if you build a tax credit, investors will come.[61] To significantly promote climate restoration, tax credits must carefully identify and incentivize restorative solutions that meet the criteria of being scalable, permanent, financeable, and equitable.

For instance, 45Q, a recent federal tax credit for sequestered carbon, rapidly boosted investment in DAC and carbon capture projects that withdraw CO_2 from the atmosphere or from point sources like coal plants.[62] However, most of that CO_2 is being used to increase oil production through enhanced oilfield recovery,[63] and of the nearly $900,000,000 in rebates granted, 87% went to firms that were not in compliance, with several failing to submit monitoring and verification plans.[64] Though well-intentioned, this credit has ultimately been counterproductive, decreasing the cost of oil but making little to no progress in reducing CO_2 levels. Recent changes to the rule make the credit more accessible to new innovators in the CDR space, but there is still room for improvement.[65] A similar tax credit that is thoughtfully designed to benefit CDR providers could have an enormous impact on growing the supply of carbon removal.[66]

Other programs like California's Low-Carbon Fuel Standard (LCFS) include some credits for sequestering CO_2 in concrete as well as for geologic sequestration, but it still focuses on carbon capture (i.e., capturing emissions at a point source) without including atmospheric carbon removal. Lessons can be drawn from both 45Q and the LCFS to develop policies to support the scaling of CDR.

[55] Wałach, D. (2021). Analysis of Factors Affecting the Environmental Impact of Concrete Structures. *Sustainability*, 13(204). https://doi.org/10.3390/su13010204

[56] CarbonStar. (n.d.). *An essential tool for decarbonizing the built environment*. CarbonStar | Counting Carbon in Concrete. Retrieved January 23, 2022, from https://www.carbonstar.org

[57] The amount of carbon dioxide emitted per ton of material produced.

[58] An EPD is the environmental "nutrition label" that reflects the findings of the concrete's life cycle analysis.

[59] Cama, T., & Green, M. (2018, 11 27). *Bipartisan group of lawmakers propose landmark carbon tax.* The Hill. https://thehill.com/policy/energy-environment/418596-bipartisan-group-of-lawmakers-propose-landmark-carbon-tax

[60] Citizens' Climate Lobby. (n.d.). *Who Supports a Price on Carbon?* Citizens' Climate Lobby. Retrieved February 2, 2022, from https://citizensclimatelobby.org/who-supports-a-price-on-carbon/

LAND-BASED SOLUTIONS

Just as governments can use direct CDR procurement to meet their net-zero targets, they can also take advantage of their public lands for carbon storage and land restoration. Adopting land management practices like planting cover crops,[67] using ground rock fertilizer,[68] and allowing livestock grazing[69] can dramatically increase soil carbon, soil health, crop yields, water retention, drought tolerance, and more. If these practices were used effectively across all public lands, the impact could remove a few gigatons of CO_2 per year while improving climate resilience and food security.[70]

REGENERATIVE AGRICULTURE

Regenerative agriculture practices have the potential to store somewhere between 1-10 Gt of CO_2 per year.[71] Regenerative practices like no-till farming, planting cover crops, and grazing livestock can store much more carbon in soils while dramatically improving the health of agricultural soils and thus increasing crop yields. These practices can also save farmers money and labor by reducing or eliminating the need to plow, reducing the need for expensive chemical fertilizers, and increasing the resilience of farmlands to suboptimal weather conditions. Yet, even the simplest practices like no-till agriculture are only practiced on about 21% of US farmlands.[72] Governments could require the use of some or all of these practices to speed up their adoption and reduce the negative consequences of current industrial farming practices like fertilizer runoff, high pesticide usage, and poor water retention.[73]

[61] Alperin, B. (2020, August 20). *INSIGHT: Tax Credit Investments Are Environmental, Social, and Governance Investments*. Daily Tax Report ®. Retrieved January 23, 2022, from https://news.bloombergtax.com/daily-tax-report/insight-tax-credit-investments-are-environmental-social-and-governance-investments

[62] Lucas, M. (2019, 02 21). *45Q creates tax credits for carbon capture. Who benefits?* Carbon180. https://carbon180.medium.com/45q-creates-tax-credits-for-carbon-capture-who-benefits-731bf382ab1d U.S.C. (2021, 10 6). §45 Q: *Credit for carbon oxide sequestration*. US code. https://uscode.house.gov/view.xhtml?req=(title:26%20section:45Q%20edition:prelim)

[63] Doukas, A., Redman, J., & Kretzmann, S. (2017, 10). *Expanding subsidies for CO_2-enhanced oil recovery: A net loss for communities, taxpayers, and the climate. Oil Change International.* http://priceofoil.org/content/uploads/2017/10/45q-analysis-oct-2017-final.pdf

[64] Buck, H. J. (2020, June 22). *Holly Jean Buck: How to Decolonize the Atmosphere.* Progressive International. Retrieved January 22, 2022, from https://progressive.international/blueprint/46253391-5b3d-4e68-bd3f-d53dc54180fd-holly-jean-buck-how-to-decolonize-the-atmosphere/en

[65] Kosar, U., & Suarez, V. (2021). Removing Forward: Centering Equity and Justice in a Carbon-Removing Future. *Carbon 180*. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/6115485ae47e7f00829083e1/1628784739915/Carbon180+RemovingForward.pdf

[66] California Air Resources Board. (n.d.). *LCFS Basics | California Air Resources Board.* California Air Resources Board. Retrieved January 24, 2022, from https://ww2.arb.ca.gov/resources/documents/lcfs-basics

[67] Bjorkman, T., Cavigelli, M., Dostie, D., Faulkner, J., Knight, L. G., Mirsky, S., & Smith, B. (n.d.). *Cover Cropping to Improve Climate Resilience*. USDA Climate Hubs. Retrieved January 24, 2022, from https://www.climatehubs.usda.gov/hubs/northeast/topic/cover-cropping-improve-climate-resilience

[68] Layton, L. (2020, July 8). *University of Sheffield scientists say rock dust could capture carbon.* The Washington Post. Retrieved January 24, 2022, from https://www.washingtonpost.com/climate-solutions/2020/07/08/spreading-rock-dust-ground-could-pull-carbon-air-researchers-say/

[69] Zoebisch, C. (2020, September 9). *Grazing for Climate.* National Sustainable Agriculture Coalition. Retrieved January 24, 2022, from https://sustainableagriculture.net/blog/grazing-for-climate/

[70] IPCC. (2019). Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-. O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, & J. Malley, Eds.). *In press.* https://www.ipcc.ch/srccl/chapter/summary-for-policymakers/

[71] Cummins, R., & Leu, A. (2021, March 8). *Best Practices: How Regenerative & Organic Agriculture and Land Use Can Reverse Global Warming.* Regeneration International. Retrieved January 24, 2022, from https://regenerationinternational.org/2021/03/08/best-practices-how-regenerative-organic-agriculture-and-land-use-can-reverse-global-warming/

[72] Creech, E. (2021, August 3). *Saving Money, Time and Soil: The Economics of No-Till Farming*. USDA. Retrieved January 24, 2022, from https://www.usda.gov/media/blog/2017/11/30/saving-money-time-and-soil-economics-no-till-farming

[73] Killebrew, K., & Wolff, H. (2010). Environmental Impacts of Agricultural Technologies. *Evans School Policy Analysis and Research (EPAR)*, 65. https://econ.washington.edu/sites/econ/files/old-site-uploads/2014/06/2010-Environmental-Impacts-of-Ag-Technologies.pdf

PETITION YOUR STATE AND LOCAL GOVERNMENT TO SUPPORT CLIMATE RESTORATION

Everyday citizens can call on public officials and other leaders to explicitly commit to restorative initiatives,[74] and in the last few years, local governments across the country have embraced a range of related resolutions.[75] For example, in December 2017, Montgomery County in Maryland declared an Emergency Climate Mobilization, which initiated large-scale efforts to remove excess atmospheric carbon and outlined greenhouse gas emissions reductions of 80% by 2027 and 100% by 2035.[76] In January 2020, Santa Clara County in California implemented its Climate Restoration Emergency Resolution, calling for the immediate mobilization of resources and labor to mitigate, restore, and prepare for climate change-related impacts.[77] And in November 2020, the City of Orlando in Florida announced its Climate Emergency Declaration, which recognizes the existence of a climate emergency and supports mobilization efforts that will return us to safe, pre-industrial levels of atmospheric carbon.[78]

Additionally, a number of schools and related organizations, including Cold Spring Elementary,[79] Oroville Union High School,[80] Alameda Unified School District,[81] and the Massachusetts Association of School Committees,[82] have passed resolutions calling for climate restoration action.

JOIN YOUR LOCAL F4CR CHAPTER

F4CR has a number of grassroots chapters committed to educating the public and local policymakers about climate restoration. There are currently 22 chapters around the world, spanning from the US to Italy, Liberia, and Australia.[83] If there is not yet a chapter in your city, reach out to us about starting your own.[84]

Additionally, there has been a surge in youth support of F4CR initiatives, with current Youth Climate Restoration Leaders from 35 countries and over 500 applicants for the program from all six continents. You can join our Youth Leaders for Climate Restoration program by applying on the F4CR website.[85]

DONATE TO THE FOUNDATION FOR CLIMATE RESTORATION

People like you power the work needed to restore a safe and healthy climate. Every dollar goes to developing the enabling environment needed for climate restoration to succeed, including:[86]

- Education and outreach efforts, including the development of lessons and resources like this White Paper;
- Support for our programs, including the Youth Leaders for Climate Restoration and Local Chapter programs;
- The creation of public-private partnerships, such as the Global Carbon Removal Partnership; and
- Grassroots advocacy for the research, development, investment, and acceleration of climate restoration solutions.

You can follow the Foundation's work by visiting our Resources page,[87] subscribing to our newsletter,[88] and following our blog.[89]

CONCLUSION

We do not need to leave dangerous, unprecedented conditions to future generations. Committing to climate restoration will place us on a dramatically different trajectory and provide us with a much-needed paradigm shift: instead of working to narrowly avoid catastrophic outcomes, we can instead drive towards the ambitious but feasible goal of a safe and thriving climate for future generations.

Using climate restoration's goal-oriented approach, we can specify the parameters, success metrics, and pathways needed to sustain humanity and the natural world. We can develop the technological capacity to safely and permanently remove and store tens of gigatons per year of atmospheric CO_2. We can design policies that prioritize the use of these restorative solutions and then accelerate their safe and equitable development, testing, implementation, investment, and scaling. All we need now is the *commitment* to do so.

To bring a safe and healthy climate within reach, we need widespread political and public demand for climate restoration. This can look like grassroots organizing in your local community, donations to the Foundation and related organizations, educating yourself with F4CR's resources, directing the young people in your life toward the Youth Leaders for Climate Restoration program, or attending F4CR webinars and events. We welcome your investment, whatever it may look like. We hope you will join the movement!

[74] Foundation for Climate Restoration. (2020). *Chapters*. Foundation for Climate Restoration. https://foundationforclimaterestoration.org/chapters/

[75] Foundation for Climate Restoration. (2021, 08 19). *Climate Restoration Gains Momentum with Adoption of Principles and Initiatives Across Globe.* Cision PR Newswire. https://www.prnewswire.com/news-releases/climate-restoration-gains-momentum-with-adoption-of-principles-and-initiatives-across-globe-301358123.html

[76] County Council for Montgomery Council, Maryland. (2017, 11 28). *Emergency Climate Mobilization.* Montgomery County Government. https://www.montgomerycountymd.gov/COUNCIL/Resources/Files/res/2017/20171205_18-974.pdf

[77] The County of Santa Clara California. (2019, 08 27). *Adopt Resolution declaring a climate emergency that demands immediate action to halt, reverse, restore and address the consequences and causes of global warming.* County of Santa Clara California. http://sccgov.iqm2.com/Citizens/Detail_LegiFile.aspx?Frame=SplitView&MeetingID=11135&MediaPosition=&ID=98193&CssClass=

[78] City of Orlando, FL. (2020, 11 9). *City of Orlando Climate Emergency Declaration*. Foundation for Climate Restoration. https://foundationforclimaterestoration.org/legislative-action/

[79] Schools for Climate Action. (n.d.). *Cold Spring Elementary School District Resolution.* https://schoolsforclimateaction.weebly.com/uploads/1/0/9/2/109230709/cold_springs_resolution-_passed.pdf

[80] Schools for Climate Action. (n.d.). *Oroville Union High School District Resolution.* https://schoolsforclimateaction.weebly.com/uploads/1/0/9/2/109230709/oroville_uhsd_climate_action_reso.pdf

[81] Schools for Climate Action. (2020). *Alameda Unified School District Resolution*. https://schoolsforclimateaction.weebly.com/uploads/1/0/9/2/109230709/alameda_usd_climate_action_resolutions.pdf

[82] Schools for Climate Action. (2019). *Massachusetts Association of School Committees Resolution.* http://schoolsforclimateaction.weebly.com/uploads/1/0/9/2/109230709/masc_climate_change_resolution_11.2019.pdf

[83] Foundation for Climate Restoration. (2022). *JOIN A LOCAL CHAPTER.* Foundation for Climate Restoration. https://foundationforclimaterestoration.org/chapters/

[84] Foundation for Climate Restoration. (2020). *Contact Us.* Foundation for Climate Restoration. https://foundationforclimaterestoration.org/contact-us/

[85] Foundation for Climate Restoration. (2022). *Become a youth leader.* Foundation for Climate Restoration. https://foundationforclimaterestoration.org/youth-leaders/

[86] Foundation for Climate Restoration. (2022). *Donate*. Foundation for Climate Restoration. https://foundationforclimaterestoration.org/donate-now/

[87] Foundation for Climate Restoration. (2022). *Resources*. Foundation for Climate Restoration. https://foundationforclimaterestoration.org/all-resources/

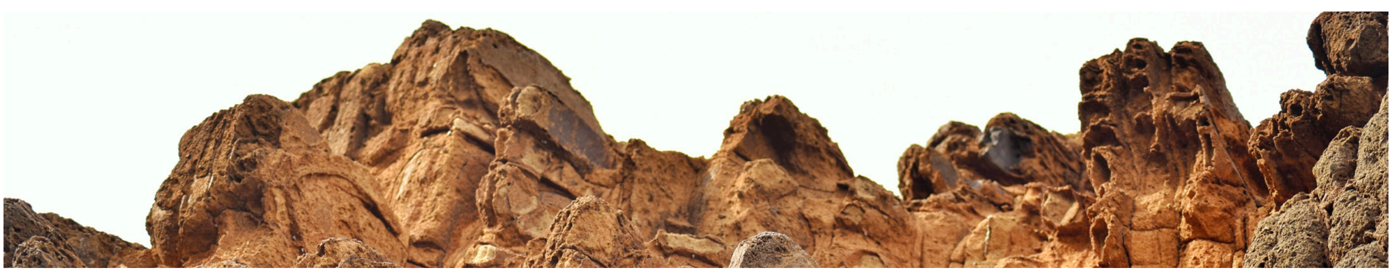
[88] Foundation for Climate Restoration. (2022). *Home*. https://foundationforclimaterestoration.org

[89] Foundation for Climate Restoration. (n.d.). *Blog*. https://f4cr.medium.com/

APPENDIX I: CLIMATE RESTORATION SOLUTIONS

Below, we utilize a scaling system of uncertain, poor, moderate, very good, and excellent to assess solutions using a climate restoration lens. These qualifiers reference only how well each solution adheres to our climate restoration criteria and do not capture each solution's advantages or disadvantages outside the context of climate restoration.

CARBON MINERALIZATION[90]	
SOLUTION	**Geologic Storage**[91]
DESCRIPTION	A natural and permanent storage solution that turns CO_2 into underground rock in less than two years.
SCALABILITY	**Excellent:** There is adequate underground space to store the excess CO_2 we remove from the atmosphere.
PERMANENCE	**Excellent:** If methods like CarbonFix are used, CO_2 injected into geologic formations is unlikely to leak at significant scale over thousands of years.[92]
FINANCEABILITY	**Uncertain, but likely good:** There is a rapidly growing voluntary market for carbon removal and there are funds available for this type of expensive CDR and storage, but it is difficult to predict what this market will look like a decade from now.
CO-BENEFITS	Fossil fuel workers possess unique skills that would be invaluable to carrying out large-scale geologic storage of carbon pollution. They have already been trained to handle the machinery to remove carbon in the form of fossil fuels from the earth, and now that training can be used to put it back.[93]
RISK AND SAFETY	Deep sedimentary rock formations, including saline aquifers and depleted oil and gas wells, are some of the safest storage sites for CO_2 and in human terms, are effectively permanent. The greatest risks include leakage of CO_2, displaced fluids, mobilized hazardous elements out of the storage reservoir, and induced ground motion, including induced seismicity.[94] Establishing long-term monitoring requirements could help ensure deployment is done safely, effectively, and permanently.[95]



[90] Carbon mineralization is the process by which carbon dioxide is removed from the atmosphere and stored in the form of solid carbonate materials.

[91] Carbfix. (n.d.). *We turn CO_2 into stone.* Carbfix. https://www.carbfix.com/

[92] Bergman, A., & Rinberg,, A. (2021). The Case for Carbon Dioxide Removal: From Science to Justice. In *CDR Primer.* Wilcox, J; Kolosz, B; Freeman, J.

[93] Scott-Buechler, C. (2021). A Progressive Platform For Carbon Removal Federal Action Plan. *Data for Progress*. https://www.filesforprogress.org/memos/carbon-removal-federal-action-plan.pdf

[94] Anderson, S.T. (2017, 01). Risk, Liability, and Economic Issues with Long-Term CO_2 Storage—A Review. *Nat Resour Res*, 26, 89–112. https://doi.org/10.1007/s11053-016-9303-6

[95] Carbon180. (2021, 08). *Removing Forward: Centering Equity and Justice in a Carbon-Removing Future.* Carbon180. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/6115485ae47e7f00829083e1/1628784739915/Carbon180+RemovingForward.pdf

CARBON MINERALIZATION	
SOLUTION	**Enhanced Weathering**[96]
DESCRIPTION	A method that involves sprinkling powdered basalt over natural ecosystems to remove atmospheric carbon dioxide while also improving soils.
SCALABILITY	**Excellent:** There is enough rock and enough storage space on Earth to lock away all excess CO_2.
PERMANENCE	**Excellent:** CO_2 is permanently stored as part of the rock.
FINANCEABILITY	**Moderate:** This process is less expensive than geologic storage, but it will still require adequate funding and a robust market.
CO-BENEFITS	Enhanced weathering can enhance the health of soils and can improve ocean pH when used along coastlines.
RISK AND SAFETY	Particles from the enhanced weathering process can be inhaled by humans and animals, causing scarring and respiratory issues. Additionally, both ocean- and land-based approaches may contaminate water from trace elements in the rock.[97]
SOLUTION	**Cementitious Materials**[98]
DESCRIPTION	A method that involves injecting CO_2 into cement mixers where it mineralizes and strengthens the resulting concrete.[99]
SCALABILITY	**Moderate:** While concrete is the most-used building material on the planet, cement is only a small fraction (10-15%) of most concrete mixes. This method can nonetheless help decarbonize an industry responsible for 8% of global annual emissions.
PERMANENCE	**Excellent:** The CO_2 is permanently stored as rock.
FINANCEABILITY	**Very good:** This method creates a valuable commercial product with a massive market. Tax credits can help negate the cost of carbon capture so that the process remains competitive and profitable.
CO-BENEFITS	**Excellent:** This method results in stronger concrete and converts the built environment from a carbon burden to a carbon sink.
RISK AND SAFETY	This method poses no risk as CO_2 is safely and permanently stored in cement and aggregate.[100]

[96] Dacey, J. (2021, 8 1). *Sprinkling basalt over soil could remove huge amounts of carbon dioxide from the atmosphere.* Physicsworld. https://physicsworld.com/a/sprinkling-basalt-over-soil-could-remove-huge-amounts-of-carbon-dioxide-from-the-atmosphere/

[97] Webb, R. M. (2020, 09). *The law of enhanced weathering for carbon dioxide removal.* Sabin Center for Climate Change Law. https://climate.law columbia.edu/sites/default/files/content/Webb%20-%20The%20Law%20of%20Enhanced%20Weathering%20for%20CO2%20Removal%20-%20 Sept.%202020.pdf

CARBON MINERALIZATION	
SOLUTION	**Synthetic Limestone**[101]
DESCRIPTION	CO_2 is used to create limestone using a chemical process similar to the one shellfish use to build their shells.
SCALABILITY	**Excellent:** Unlike cement, limestone makes up the majority of concrete mixes. The limestone in concrete can thus store an enormous amount of—and potentially all—excess CO_2.
PERMANENCE	**Excellent:** The CO_2 is permanently stored as rock.
FINANCEABILITY	Same as cementitious materials above.
CO-BENEFITS	This method reduces the need for quarries and mitigates transportation emissions since it can be produced close to the end-use point.
RISK AND SAFETY	Same as cementitious materials above.

ABIOTIC[103] OCEAN-BASED SOLUTIONS[102]	
SOLUTION	**Alkalinity Enhancement**[104]
DESCRIPTION	Ocean alkalinity enhancement involves accelerating natural weathering processes by introducing crushed rock directly to land or oceans.
SCALABILITY	**Excellent:** There is no apparent limit to scaling beyond logistical issues.[105]
PERMANENCE	**Excellent:** Because this method is part of the geologic carbon cycle, it will take millions of years for the carbon to cycle back out into the atmosphere.
FINANCEABILITY	**Very good:** As of now, depending on the method used, ocean alkalinity enhancement costs between \$20-\$600/ton.[106] However, it is estimated that costs will decline to \$10/ton and will decrease further as this method scales and as carbon markets expand.
CO-BENEFITS	This method improves ocean pH, which can mitigate the negative ecological and biodiversity impacts of climate change, like coral bleaching.
RISK AND SAFETY	Weathering of alkaline minerals may release byproducts that can either negatively or positively affect the marine ecosystem and change the composition of phytoplankton communities. Lab and field experiments are needed to fully understand all potential environmental impacts.

[98] CarbonCure. (2021). *Reducing Carbon, One Truck At A Time.* CarbonCure. https://www.carboncure.com
Solidia. (n.d.). Solidia. https://www.solidiatech.com/

[99] Every cubic meter of concrete produced with this carbon cure technology keeps an average of 25 pounds of CO_2 emissions from entering the atmosphere. An average high-rise building built with CarbonCure would avoid approximately 1.5 million pounds of CO_2 emissions, the equivalent carbon absorption of 888 acres of forest in a year.

[100] Blue Planet Systems. (n.d.). *Permanent CarbonCure technology*. Blue Planet Systems. https://www.blueplanetsystems.com

ABIOTIC OCEAN-BASED SOLUTIONS	
SOLUTION	**Artificial Downwelling**[107]
DESCRIPTION	This method involves pumping atmospheric CO_2 down to the deep ocean for storage for up to hundreds to thousands of years. Downwelling in polar regions would laterally pull warmer waters poleward, which would then cool and absorb more CO_2 from the atmosphere.
SCALABILITY	**Uncertain, but likely moderate:** More research is needed, but initial cost estimates are low.
PERMANENCE	**Uncertain:** More research is needed.
FINANCEABILITY	**Poor:** The cost of CO_2 drawdown varies greatly by approach, but it can cost $177/ton for CO_2 that increases salinity and between $4,000 to $20,000/ton for CO_2 used to cool seawater due to the high energy requirements.
CO-BENEFITS	This method can be used to mitigate oxygen depletion in hypoxic areas or dead zones.
RISK AND SAFETY	As artificial downwelling for CO_2 storage has not been pursued beyond a theoretical framework, environmental impacts are unknown. However, changing seawater temperature and salinity are likely to affect phytoplankton communities, and temperature changes may influence weather. The marine infrastructure needed for downwelling may contribute to marine debris if damaged.[108]

BIOTIC OCEAN-BASED SOLUTIONS[109]	
SOLUTION	**Macroalgal Cultivation**[110]
DESCRIPTION	Photosynthesis by macroalgae converts dissolved CO_2 into organic carbon. This can be stored in the ocean's depths or used in commercially viable products.
SCALABILITY	**Very good:** While there is adequate space for macroalgae to take up all our excess CO_2, logistics would be very challenging given that 1-2% of ocean area would be required.
PERMANENCE	**Very good:** According to initial modeling, this method is permanent if implemented correctly in the deep ocean. Otherwise, coastal kelp forests and those where the kelp isn't sunk deep enough may not lock up CO_2 for very long.
FINANCEABILITY	**Very good:** Macroalgae can be sold for use in large and growing industries like pharmaceuticals, cosmetics, and food. However, a percentage of macroalgae should be sold so that it can be locked away more permanently in the deep ocean.
CO-BENEFITS	This method restores habitats for marine life in ocean deserts.
RISK AND SAFETY	Risks include the potential genetic mixing with local species, the spread of diseases and parasites, and the creation of stepping stones for invasive marine species. Large-scale cultivation would also likely result in nutrient competition with the local ecosystem, and the harvesting of wild macroalgae could negatively impact co-occurring species.

BIOTIC OCEAN-BASED SOLUTIONS	
SOLUTION	**Artificial Upwelling**[111]
DESCRIPTION	Artificial upwelling moves deep, nutrient-rich water upwards to stimulate photosynthesis by the phytoplankton and macroalgae in sunlit surface waters.
SCALABILITY	**Uncertain, but likely very good:** This method helps stimulate microalgae blooms, which can increase the amount of CO_2 that gets locked up by photosynthesis and then sunk to the deep ocean. However, it is not entirely clear how much CO_2 actually sinks to the deep ocean to be locked away permanently.
PERMANENCE	Same as macroalgal cultivation above.
FINANCEABILITY	**Uncertain:** Cost estimates vary widely and depend on the materials and methods used. However, if paired with another method, like macroalgae cultivation, the cost of artificial upwelling could be covered by the sale of kelp.
CO-BENEFITS	This method supports the growth of microalgae, which can revitalize ocean deserts.
RISK AND SAFETY	Given the absence of large-scale studies, the ecological impacts of this method are unknown.

[101] Carbon8 Systems. (n.d.). *Accelerated Carbonation Technology (ACT).* Carbon8 Systems. https://c8s.co.uk/what-is-act/ and Blue Planet Systems. (n.d.). *Permanent carbon capture*. Blue Planet Systems. https://www.blueplanetsystems.com

[102] Ocean-based solutions rely primarily on photosynthesis to remove atmospheric CO_2 and can store this CO_2 deep within the ocean for as long as a millennium.

[103] Ocean CDR. (2021). *Ocean CDR approaches boosting Earth's natural carbon pumps.* Ocean CDR. https://oceancdr.net/approaches

[104] Ocean CDR. (2021). *Alkalinity Enhancement.* Ocean CDR. https://oceancdr.net/approaches/alkalinity

[105] Ocean CDR. (2021). *Alkalinity Enhancement.* Ocean CDR. https://oceancdr.net/approaches/alkalinity

[106] Ocean CDR. (2021). *Alkalinity Enhancement.* Ocean CDR. https://oceancdr.net/approaches/alkalinity

[107] Ocean CDR. (n.d.). *Artificial Downwelling.* Ocean CDR. Retrieved Enero 24, 2022, from https://oceancdr.net/approaches/downwelling

BIOTIC OCEAN-BASED SOLUTIONS	
SOLUTION	**Ocean Fertilization**[112]
DESCRIPTION	Fertilizing nutrient-poor surface waters with nutrients like iron, phosphorus, and nitrogen can stimulate photosynthesis and fix excess CO_2 in living biomass of phytoplankton and macroalgae.
SCALABILITY	**Uncertain:** Initial findings show that getting microalgae to the mid-ocean, rather than deep ocean, would be enough to successfully store large amounts of carbon for the long term. However, more studies and testing are needed to fully assess scalability.
PERMANENCE	**Uncertain:** This is an area of active research, but some experts believe carbon fixed using this method can be stored for millennia.
FINANCEABILITY	**Uncertain:** While this method can be financed through the sale of fishing licenses, carbon removal credits, or government funding for fishery restoration, to implement this method safely could be very expensive.
CO-BENEFITS	This method can support the growth of microalgae, which can revitalize ocean deserts.
RISK AND SAFETY	Due to inadequate testing, potential risks are not fully understood, but the ecological impact could be enormous. Scientists are concerned about toxic algal blooms, oxygen depletion in mid-waters, altered marine food web structure, nutrient depletion, and the release of greenhouse gasses.
SOLUTION	**Blue Carbon Management**
DESCRIPTION	Blue Carbon Management uses coastal ecosystems like mangroves, peatlands, kelp forests, and sea grasses to take in and lock up CO_2.
SCALABILITY	**Poor:** Although Blue Carbon ecosystems serve as critical carbon sinks, they do not represent a significant opportunity for additional CO_2 removal.
PERMANENCE	**Poor:** Because carbon cycling in coastal ecosystems happens on biologic timescales (i.e., decades to centuries), this method does not meet our standard for permanence.
FINANCEABILITY	**Uncertain:** While coastal ecosystem restoration could result in increased marine life, tourism, and other benefits, it is not clear how profitable this activity would be.
CO-BENEFITS	This method can restore habitats for endangered species, mitigate coastal erosion, and reduce the impacts and intensity of storm surges, tsunamis, and other extreme weather. Additionally, these areas can be an important food source and can serve as wood production, ecotourism, and education sites for local communities.[113]
RISK AND SAFETY	Peatlands have long been exploited, and about 15% have already been drained. The draining of peatlands prevents the storage of carbon and also releases any stored carbon into the atmosphere. By investing in peatland restoration, peatlands can become a more viable carbon storage site.[114]

[108] Ocean CDR. (n.d.). *Artificial Downwelling.* Ocean CDR. Retrieved Enero 24, 2022, from https://oceancdr.net/approaches/downwelling

[109] Ocean CDR. (2021). *Ocean CDR approaches boosting Earth's natural carbon pumps.* Ocean CDR. https://oceancdr.net/approaches

[110] Ocean CDR. (2021). *Macroalgal Cultivation.* Ocean CDR. https://oceancdr.net/approaches/macroalgal

[111] Ocean CDR. (2021). *Artificial Upwelling.* Ocean CDR. https://oceancdr.net/approaches/upwelling

[112] Ocean CDR. (2021). *Ocean Fertilization.* Ocean CDR. https://oceancdr.net/approaches/fertilization

[113] International Peatland Society. (n.d.). *Peatlands and Society.* International Peatland Society. https://peatlands.org/peatlands/peatlands-and-society/

[114] Xu, B. (2021, April 8). How scientists are restoring boreal peatlands to help keep carbon in the ground. The Conversation. Retrieved February 3, 2022, from https://theconversation.com/how-scientists-are-restoring-boreal-peatlands-to-help-keep-carbon-in-the-ground-145290

NATURAL LAND-BASED SOLUTIONS	
SOLUTION	**Soil Carbon Management**
DESCRIPTION	Soil carbon sequestration for CDR involves making changes to land management practices that increase the carbon content of soil, resulting in a net removal of CO_2 from the atmosphere.
SCALABILITY	**Very good:** This could be scaled to remove tens of Gt per year depending on the approach taken.
PERMANENCE	**Uncertain:** Permanence is highly variable depending on the approach taken, the length and consistency of implementation, and external factors like natural disasters.
FINANCEABILITY	**Moderate:** This varies depending on the approach taken. Some approaches, like no-till agriculture, are inexpensive with high returns.
CO-BENEFITS	This method can improve crop yields and water cycling on agricultural lands and can support healthy biodiversity and ecosystem resilience on non-agricultural land. Many methods that result in increased soil carbon sequestration also reduce our need for fertilizers, pesticides, and herbicides.
RISK AND SAFETY	The integration of new practices into ongoing operations is perceived as economically risky. This risk can be mitigated with incentives from the federal government and through potential market mechanisms, including procurement incentives, payment for ecosystem services, tax credits, offset mechanisms, or direct payments for carbon storage.[115]
SOLUTION	**Regenerative Agriculture**
DESCRIPTION	Regenerative agriculture is a suite of practices that includes no-till agriculture, planting cover crops, and compost application, all of which increase soil carbon and improve agricultural productivity.
SCALABILITY	**Very good:** The estimates vary, but carbon removal could be around 1-10 Gt/yr.
PERMANENCE	**Moderate:** Changes in land management or external factors, like drought and wildfires, can re-release stored carbon.
FINANCEABILITY	**Very good:** This method is inexpensive and returns from improved crop yields are generally high.
CO-BENEFITS	This method improves resilience of farmlands to some impacts of climate change, especially droughts. It also improves the ability of soils to appropriately drain and retain water.[116]
RISK AND SAFETY	Regenerative agricultural practices are used with soil carbon sequestration and tend to be much safer than traditional agricultural methods. Regenerative agriculture relies minimally, if at all, on pesticides, herbicides, and insecticides, and because there is little reliance on heavy machinery, there is a lower risk of dangerous injury.[117]

[115] Carbon 180. (n.d.). Leading with Soil: Scaling Soil Carbon Storage in Agriculture. *Carbon 180*. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/5eaa30d12c3a767e64c3845b/1588211922979/LeadingWithSoil_Final+Text.pdf

[116] Brazeau, M. (2021, May 18). *The central challenge for regenerative agriculture advocates: Not undermining the movement by 'overselling' its limited and targeted advantages.* Genetic Literacy Project. Retrieved January 24, 2022, from https://geneticliteracyproject.org/2021/05/18/the-central-challenge-for-regenerative-agriculture-advocates-not-undermining-the-movement-by-overselling-its-limited-and-targeted-advantages/

[117] Xiang-Yang, Y., Guang-Guo, Y., & Kookanaa, R. S. (2009, 07). Reduced plant uptake of pesticides with biochar additions to soil. *Chemosphere*, 76(5), 665-671. https://www.sciencedirect.com/science/article/abs/pii/S0045653509004226

NATURAL LAND-BASED SOLUTIONS	
SOLUTION	**Afforestation, Reforestation, and Forestry Land Management**
DESCRIPTION	Afforestation refers to the establishment of new trees and forest cover in an area where forests have not existed recently. Reforestation refers to the replanting of trees on recently deforested land. Improved forest management refers to the active modification of forestry practices to promote greater forest biomass and carbon storage.
SCALABILITY	**Uncertain:** Some approaches could remove up to 12 Gt/yr, but increased demand for land would threaten food production and biodiversity and thus inhibit scaling.
PERMANENCE	**Poor:** Even with rigorous monitoring and strong contractual agreements around land use, the maximum duration of storage is likely around 100 years, which is still orders of magnitude less than what is offered by geological or mineral storage.[118]
FINANCEABILITY	**Poor:** Some financing can come from the voluntary carbon market, but these methods present unique economic risks. Additionally, most estimates indicate that it would be more costly to restore forests than to preserve existing ones.[119]
CO-BENEFITS	Forest projects benefit both biodiversity and conservation, improve ecosystem goods and services, like water purification and pollination, and support the livelihoods of local and Indigenous communities.[120]
RISK AND SAFETY	Forests only work well as carbon sinks if they are properly located, composed of regionally-appropriate species, and the trees survive.[121] The risk of their becoming a carbon source increases as the frequency and intensity of extreme weather events rises due to climate change.[122]
SOLUTION	**Biochar**
DESCRIPTION	Biochar is a charcoal-like substance that is made by burning organic material from agricultural and forestry biomass in a controlled process called pyrolysis.
SCALABILITY	**Moderate:** Recent estimates of biochar's potential scale range from 1.1 to 3.3 Gt CO_2 removal per year by 2030.[123]
PERMANENCE	**Uncertain:** More research is needed.
FINANCEABILITY	**Uncertain:** More research is needed.
CO-BENEFITS	This method improves soil health and quality, increasing crop yields and the biomass available for additional carbon sequestration.
RISK AND SAFETY	Biochar can be carbon-negative only if it is used in the right type of soil, climate conditions, crop systems, etc. There is also a risk that biochar can absorb chemicals like polyaromatic hydrocarbons, toxic metals, and other organic and inorganic contaminants.[124]

[118] Bergman, A., & Rinberg, A. (2021). Harms and co-benefits of large-scale CDR deployment. In CDR Primer. J Wilcox, B Kolosz, & J Freeman. https://cdrprimer.org/read/chapter-1#sec-1-6

[119] CDR Primer. (2020). *Chapter 2: The building blocks of CDR systems*. CDR Primer. https://cdrprimer.org/read/chapter-2#sec-2-3

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NATURAL LAND-BASED SOLUTIONS	
SOLUTION	**Biomass Energy with Carbon Capture and Sequestration (BECCS)**
DESCRIPTION	BECCS couples the natural photosynthetic growth of plants with the engineered production of bioenergy. BECCS is considered a CDR system when bioenergy is provided alongside the capture and storage of carbon such that the net balance of carbon released during biomass production, transport, conversion, and utilization is negative.[125]
SCALABILITY	**Moderate:** BECCS runs into scalability (and equity) issues if biomass comes from sources other than waste (e.g., rice husks). If biomass is grown specifically for BECCS, the land required could compete with agriculture and other land use needs, like food production.[126]
PERMANENCE	**Excellent:** BECCS involves permanent, geologic storage of captured CO_2.[127]
FINANCEABILITY	**Moderate:** Cost estimates range from $15 to $400/ton of CO_2 but this can be offset if the energy that is produced as a byproduct of BECCS is sold at a profit. However, this depends on factors such as the effectiveness of the carbon capture plant, transportation, and biomass supply.
CO-BENEFITS	Potential benefits include job creation, air quality improvement, an increase in tax revenue base, and the removal of hundreds of thousands of tons of carbon from the atmosphere per year.[128]
RISK AND SAFETY	BECCS deployment at scale competes for land and labor resources, which may result in higher food prices and increased food insecurity.[129]

TECHNOLOGICAL LAND-BASED SOLUTIONS	
SOLUTION	**Direct Air Capture (DAC) or Direct Air Carbon Capture (DACC)**
DESCRIPTION	DAC refers to technologies that use a chemical approach to capture CO_2 from ambient air.[130]
SCALABILITY	**Moderate:** While there are no strict biophysical constraints on scaling this method, extensive deployment will require large amounts of materials, land, and associated infrastructure that can cause greenhouse gas emissions and other negative impacts.[131]
PERMANENCE	This depends on how the captured CO_2 is used: if used for mineralization, it is excellent, but if used for jet fuel, it is poor.
FINANCEABILITY	**Moderate:** DAC is currently expensive at $600/ton of CO_2, but the rapidly growing voluntary market for carbon removal may make more funds available for this kind of CDR and storage.[132]
CO-BENEFITS	This method is expected to create about 300,000 jobs in the United States over the next 30 years.[133]
RISK AND SAFETY	Technologies used by companies like Carbon Engineering capture CO_2 from the air in a closed “chemical loop” that reuses the same captured chemicals over and over. This process is non-volatile, non-toxic, and meets environmental health and safety standards.[134]

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