SOLUTION SERIES

FOUNDATION FOR
CLIMATE
RESTORATION

# DIRECT AIR CAPTURE

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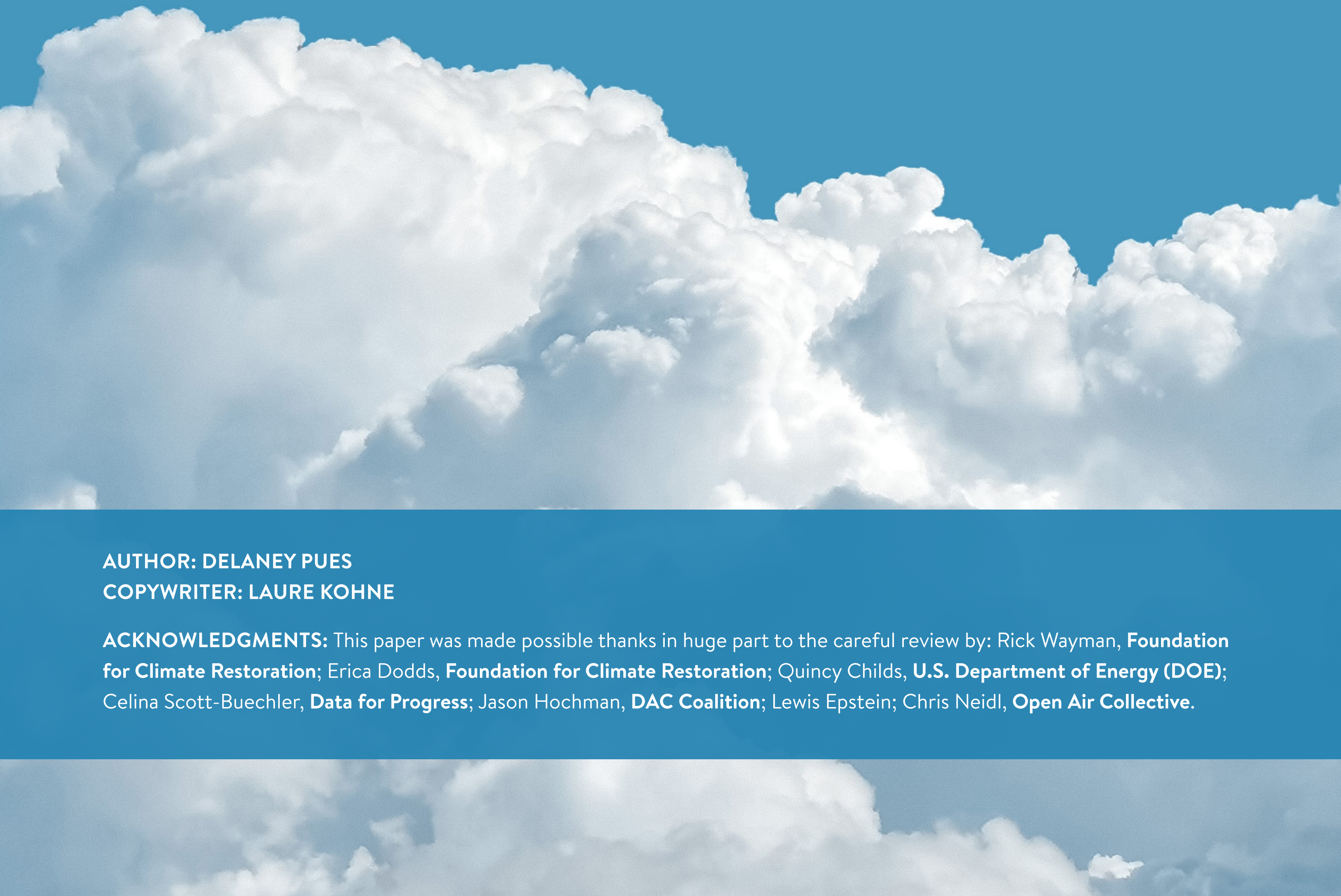

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## OVERVIEW

The Foundation for Climate Restoration is committed to restoring a climate that supports the long-term survival of humanity and our natural world. To this end, the Foundation's explicit goal is to reduce atmospheric carbon dioxide to preindustrial levels of 300 parts per million (ppm) by 2050.

This is the first installment of the Foundation's Solution Series, which examines a diverse portfolio of natural and technological approaches that can remove $CO_2$ from our atmosphere and return us to safe, preindustrial levels of carbon.

In this paper, we explore Direct Air Capture (DAC) through a climate restoration lens. We use a US-based exemplary focus while recognizing the global strategy needed to restore the climate. We discuss DAC's capacity to achieve scalable, financeable, durable, and equitable outcomes and then provide ways for readers to advocate for its safe and thoughtful implementation.

## INTRODUCTION

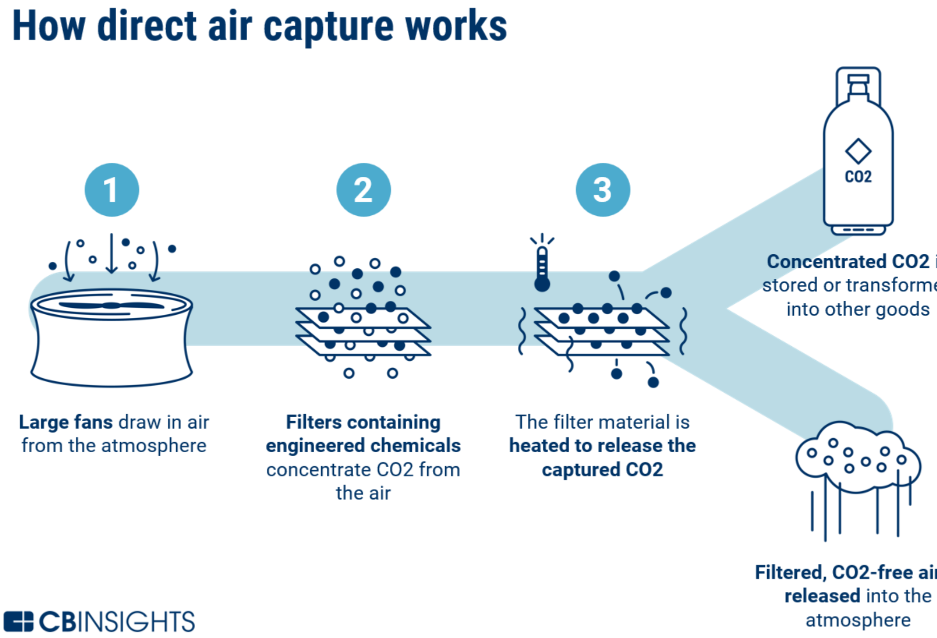
DAC is a type of Carbon Dioxide Removal (CDR), which refers to any process that removes carbon dioxide from the atmosphere and stores it for decades, centuries, or millenia.[1] DAC involves capturing carbon from the atmosphere, rather than from a point-source, like a smoke-stack. This captured $CO_2$ can be permanently stored underground in deep geological formations or used in products such as synthetic fuels or carbon-negative concrete.

Most current DAC methods are in the early stages of development and remain energy-intensive. With adequate funding, DAC has the capacity to create 300,000 new jobs in the US once scaled and could contribute significantly to economic growth.[2] In the next decade, significant investment and policy interventions are needed to scale DAC at the rate needed to reach gigaton scale and drive down costs.[3] With further research and refinement, the DAC process itself could result in near-zero emissions and potentially make a meaningful contribution to restoring our climate to preindustrial levels of $CO_2$.[4]

## HOW DAC WORKS

DAC technology pulls in ambient air, extracts the carbon dioxide from it through a series of chemical reactions, and then returns the rest of the air to the environment.[5] Alternatively, some DAC processes use the enhanced weathering cycle[6] where the natural minerals react with atmospheric carbon and filter out $CO_2$, which is then heated for safe and permanent storage.[7] The result is $CO_2$ in a pure, compressed form that can be stored underground or reused.[8]

[5] This process mimics the way plants and trees photosynthesize, but DAC does it much faster and with a smaller land footprint.



*Click for image source.*[9]

DAC plants provide a scalable solution for removing legacy $CO_2$ from the atmosphere at gigaton-scale in order to restore the climate. They are location-agnostic, so they can be built almost anywhere and in most climates. They have flexible configurations and can thus be customized, but they are most economical at an industrial scale.[11]

Carbon Engineering,[12] Climeworks,[13] Global Thermostat,[14] the Center for Negative Emissions at Arizona State University,[15] and Heirloom[16] are working on some of the most promising DAC technologies to date, with a diverse set of technology, processes, applications, and companies beginning development each day.[17]

*Click for image source.*[10]

## DAC VS. CCS: WHAT'S THE DIFFERENCE?

DAC is not the same as Carbon Capture and Storage (CCS), which captures $CO_2$ at a point-source from a smokestack. CCS can be attached to emitters like power plants, cement producers, and other carbon-intensive industries. In contrast, DAC captures $CO_2$ from the emissions already in the atmosphere. While CCS can play a role in decarbonizing hard-to-abate sectors, it removes fewer emissions than facilities emit overall and thus cannot be considered carbon removal.[18] Climate restoration will certainly require global decarbonization, and to that end, CCS is helpful. However, we must focus on methods like DAC to remove legacy emissions and reach pre-industrial levels of $CO_2$.

## DAC AS A CLIMATE RESTORATION SOLUTION

Because climate restoration requires the removal of 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 fairly distributes the benefits and burdens to all, regardless of income, race, and other characteristics.

### DURABILITY[19]

DAC's durability depends on how the captured $CO_2$ is used. For example, if the carbon is used for mineralization and stored in large geologic reservoirs, then it can be stored for centuries.[20] If it is used for jet fuel, the captured carbon will be released back into the atmosphere and is thus not taken out of circulation permanently.

### SCALABILITY[21]

Once scaled, leading studies suggest that DAC technologies can remove as much as 5 Gt of $CO_2$ per year by 2050[22] and as much as 40 Gt per year by the end of the century.[23] A more recent study suggested DAC could remove as much as 10 to 20 Gt of $CO_2$ per year if coupled with a renewable energy source and sited near geologic storage.[24] However, to reach gigaton scale by 2050, DAC will require annual growth rates of nearly 50%[25] and will need a significant amount of land, materials, and associated infrastructure, all of which can cause greenhouse gas emissions and other negative impacts.[26]

DAC appears more easily scalable than some other CDR approaches, like forest restoration or BECCS, which can be more land and water-intensive.[27] DAC does not require arable land,[28] so plants will not compete with land needed for food production.[29] This flexibility also means that plants can be built near geologic storage locations, which will reduce transportation costs.[30] However, the latest IPCC report noted that DAC will require significant water as it scales, which may impact food prices most dramatically for vulnerable populations in the Global South.[31] While some DAC technologies produce water as a by-product, the quantities produced are not sufficient to offset total water loss.

[28] Arable land is land used for growing crops.

Increasing removals to gigaton scale will also require significant amounts of energy.[32] Maximizing the potential of DAC thus requires coupling capture plants with low-carbon or carbon-free energy,[33] which can be achieved with approaches like electro-swing adsorption.[34] Scaling up DAC will also require regional and global supply chains to be expanded to accommodate large quantities of steel and concrete.[35] DAC's energy requirements underscore the urgency of shifting to renewable energy and the necessity of using a broad portfolio of restorative solutions to remove and store 50 Gt of legacy carbon per year.

## FINANCEABILITY[36]

DAC without sequestration is currently expensive with costs ranging from \$250 to \$600/tCO₂.[37] Unlike solar energy, which scaled quickly thanks to public incentives and market demand, there is no obvious private sector market to drive deployment.[38] However, the rapidly growing voluntary carbon market,[39] whose present size is only a fraction of what is ultimately needed, may make more funds available for this kind of CDR and storage.[40] In order to reach the gigaton-scale required for climate restoration, we will likely need compliance markets[41] given the uncertainty about future prices, market size, and reliability of carbon removal. However, the lower cost alternatives for carbon removal make it likely that voluntary markets will play only a limited role once DAC is scaled.[42]

Climeworks is aiming to reach \$200 to \$300 per ton by 2030,[43] Carbon Engineering has a levelized cost[44] per ton ranging from \$94 to \$232,[45] and Heirloom is projected to hit \$50/ton for carbon removal by 2035.[46] These costs can be further reduced through supportive policies, market development, commercialization, and mass deployment. Early initiatives and policy support to develop, pilot, and deploy DAC can help us explore its potential[47] and make progress towards a total system cost of less than \$150/ton[48] beyond 2030.[49] An investment of \$700 million could buy down the expense of DAC implementation[50] so that it costs only \$100/ton and is considered economically viable enough to remove 10% to 20% of hard-to-abate emissions.[51]

## EQUITY[52]

The deployment of DAC can be variable and is in only the beginning stages of deployment, making a thorough equity analysis difficult. Nonetheless, this section proposes ways that DAC can be implemented equitably and identifies potential challenges to its equitable deployment.[53]

Regardless of where DAC is deployed, its presence can impact surrounding communities, underscoring the need for procedural justice within its implementation. Stakeholders should be empowered to meaningfully participate in all decision-making processes, should be compensated for their input and time investment, and should be given the final approval of projects.[54] Additionally, stakeholders should be offered site-specific technical assessments and community education so that they can make informed decisions about the role DAC may play in their community before projects are underway.[55] Impacted communities should be able to shape project features, outcomes, and alternatives through a robust community engagement and co-creation process that gives them veto power as needed.[56]

Equitable DAC deployment will certainly require distributive justice, and special attention should be paid to equity issues related to DAC siting, the storage of $CO_2$, land tenure and land rights, and pollution from the construction process, among others. More specifically, project-by-project assessments should consider: storage and leakage risks to surrounding communities; the co-location of geologic storage to reduce transportation infrastructure needs; an environmental site suitability analysis;[57] co-location with waste heat streams or excess wind and solar curtailment to minimize the energy footprint; and air quality impacts from construction.[58] Additionally, the implementation of DAC technology can result in inequities,[59] so those spearheading DAC projects should ensure that local communities and the often remote technology developers share benefits and costs equitably.[60]

As we learn more about the implications of deployment, policymakers should require environmental justice safeguards, high-road labor standards, prevailing wages, domestic manufacturing stipulations, and local job creation for DAC projects in the interim.[61] Government policy should also consider: tangible non-climate benefits to communities harmed by polluting industries; the potential co-benefits of reducing air pollutants; the remediation of legacy environmental impacts;[62] and mechanisms, like procurement, to ensure that all DAC projects maximize social benefits.[63]

## INTEGRATING CO-LOCATION BENEFITS AT THE COMMUNITY LEVEL

Though not scalable as a restorative solution, the coupling of DAC and Heating, Ventilation, and Air Conditioning (HVAC) systems has been shown to improve indoor air quality. Additionally, HVAC-DAC coupling can reduce the energy demand of buildings and make use of $CO_2$ resources transported in the built environment. HVAC-DAC coupling is not yet commercially available, and it may ultimately prove to be impractical because of the energy and sequestration cost, though many startups and researchers are developing such technology.[64] With air pollution contributing to almost 4 million deaths per year,[65] facilitating HVAC-DAC coupling through strategic DAC placement can further distributive justice by improving air quality and reducing pollution for surrounding communities. Approaching DAC with co-location opportunities in mind underscores the importance in breeding innovation at the community level through means of citizen science and community ownership models. Finding ways like the HVAC-DAC coupling to bring benefits to surrounding communities will be crucial in ensuring distributive justice.

In terms of reparative justice, DAC implementation can be used to redistribute resources and dismantle environmentally harmful systems through climate reparations.[66] Given that the Global North is responsible for 50 percent of all the planet-warming emissions released over the past 170 years,[67] it should leverage its financial and technological resources to fund the removal of

[66] Climate reparations is the effort to assess the harm caused by the past emissions of the major polluters and to improve the lives of the climate vulnerable through direct programs, policies and/or mechanisms for significant resource transfers.

legacy carbon through DAC and other CDR solutions, while working urgently to dramatically reduce current greenhouse gas emissions. The resulting DAC economies should redistribute benefits to the Global South through high-quality jobs, joint ventures and investment, and community access to renewable energy.[68] As DAC scales, every effort should be made to enable the Global South and other climate-vulnerable communities to contemplate a better livelihood in light of present and future climate challenges.[69]

Finally, because scaling DAC requires reliable access to clean energy, its implementation can further transformative justice by incentivizing and accelerating the shift to low-carbon energy generation.[70] The Department of Energy (DOE) has emphasized the importance of placing at least two DAC hubs in fossil fuel-producing regions so that the industry's existing skill set can be leveraged (i.e., industry expertise can be applied to capturing, transporting, storing, and utilizing $CO_2$) and so that the transition from fossil fuel production is economically practical for reliant communities.[71] Equitable DAC deployment thus has the capacity to replace polluting industries and transition us more swiftly to a clean energy economy.

## HOW TO SCALE DAC

### RESEARCH AND DEVELOPMENT OPPORTUNITIES

Policy intervention and significant investment in DAC in the next decade can drive down the costs of industrial-scale deployment,[72] and we can use the same learning-by-doing approach that proved successful when scaling solar energy in the early 2000s.[73] Continued government funding for R&D, specifically in the US, has driven significant private sector interest and investment in DAC technologies.[74] Capital support through investment tax credits, tax-advantaged financing structures, DOE loans, accelerated depreciation, and public competitions can incentivize refinement of DAC technologies and drive down the cost barriers to building new plants.[75] Private sector prizes can also drive innovation and development, like Elon Musk's XPRIZE competition, which will award $100 million to competitors with the top CDR designs.[76] Deployment policy support must be accompanied by well-designed innovation policy to aid in research and development.[77] The DOE recently provided $12 million in funding for six R&D projects that decrease the cost barrier of deployment, and increase design and operational efficiency to ensure that the removal process is carbon negative.[78]

### POLICY OPPORTUNITIES

Policy is a critical component of large-scale DAC deployment because geologic storage has no market value in the absence of a policy-induced price for removing $CO_2$ emissions.[79] Near-term policy support can further reduce the costs of DAC facility installations to make it a viable solution at the gigaton scale.[80] To that end, research shows that direct operations incentives are the most effective way of driving the development and deployment of DAC.[81] This can include production tax credits, cash grants and direct payments, government procurement (e.g., reverse auctions), government-owned and contractor-operated facilities, and emissions pricing and standards (e.g., California's Low Carbon Fuel Standard).[82]

Notably, the DOE launched the Carbon Negative Shot in 2021 with the aim of accelerating CDR solutions, including DAC, that lower the cost of removal to $100/ton while prioritizing high-quality lifecycle accounting, equity and justice, and durable storage for at least 100 years.[83] Most recently, the United States has passed the Infrastructure Investment and Jobs Act, which includes a $3.5 billion Regional Direct Air Capture Hubs program that will meaningfully engage with local communities, environmental and climate justice organizations, tribal nations, labor groups, industry leaders, and academics as it scales CDR technologies.[84]

### ADVOCACY OPPORTUNITIES

Citizen-advocates can build awareness of DAC more formally through membership in the Foundation's Local Chapters[85] or through the Youth Leaders for Climate Restoration program.[86]

## CONCLUSION

Although restoration-scale deployment of DAC presents a number of challenges, it has the potential to contribute, as part of a portfolio of solutions, to the ambitious but feasible goal of climate restoration. Its successful implementation will require further research and development that emphasizes cost reduction, increased technological efficiency, industrial-scale investment, and the shift to 100% renewable energy. We can ensure its equitable deployment by centering frontline communities in the decision-making process and by requiring that both its climate and non-climate benefits flow to the climate vulnerable. Government has the greatest leverage in operationalizing gigaton-scale DAC, so advocates should petition government leaders for increased research, funding, and commitment to its safe and equitable deployment.

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