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# Investing in Climate Innovation: The Environmental Case for Direct Air Capture of Carbon Dioxide

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**MAY 2020**

**A White Paper by the Bipartisan Policy Center's Direct Air  
Capture Advisory Council**

**Bipartisan Policy Center**

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## **DISCLAIMER**

The findings and conclusions expressed herein do not necessarily reflect the views or opinions of BPC, its founders, its funders, or its board of directors.

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Direct air capture refers to technologies that remove carbon dioxide from the ambient air. In contrast to natural or biological mechanisms for capturing CO<sub>2</sub>—growing trees is the best known example—DAC systems typically rely on a combination of mechanical, chemical, and thermal processes to first separate CO<sub>2</sub> from the air and then concentrate the CO<sub>2</sub> so that it is suitable for use in other applications or for geological storage.<sup>1</sup> The appeal of DAC, if the technology can be successfully commercialized on a large scale, is that it would provide a means for directly reducing CO<sub>2</sub> in the atmosphere and thus could be a valuable addition to the tools at our disposal for managing rapidly escalating climate risks.

The Bipartisan Policy Center launched its Direct Air Capture Advisory Council in 2019 to explore the role that DAC technology could play in the transition to a net-zero carbon economy. The Council's 13 members include leaders from academia, the private sector, labor, and the NGO community. This white paper, the first in a series of three, makes the environmental case for an ambitious, targeted, and diversified program of near-term investment in DAC as part of a comprehensive strategy for achieving international climate goals over the next several decades and beyond.

Fundamentally, our support for expanded efforts to develop DAC technology rests on four key observations:

- **Carbon removal capability is likely necessary.** Given current emissions trends and taking into account the quantity of greenhouse gases currently in the atmosphere, the international scientific community is increasingly of the view that CO<sub>2</sub> removal is necessary, along with aggressive action to reduce emissions, to limit warming this century to below 2°C.
- **Some sources of distributed greenhouse gas emissions will be difficult to eliminate.** If the goal is to drive toward near net-zero global carbon emissions by mid-century, the case for carbon removal options becomes even stronger because of the difficulty of fully decarbonizing certain energy-use sectors (e.g., long-haul air travel) and of eliminating emissions from other, non-energy sources (e.g., agriculture). Carbon capture and storage is unlikely to be cost-effective and technologically feasible for some of these dispersed, hard-to-decarbonize sources because it is primarily suited to large point sources of emissions.
- **DAC should be viewed as part of a portfolio of carbon removal strategies.** As a complement to other carbon dioxide removal strategies (notably, tree restoration and soil carbon storage), DAC offers potentially important advantages in terms of

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<sup>1</sup> The technology capability and resource potential to implement geological storage of captured CO<sub>2</sub> on a large scale is considered relatively well established. Estimates of global geologic storage capacity are on the order of 2 trillion tons. (See: "Storage: Storing carbon dioxide." Global CCS Institute. 2019. Available at: <https://www.globalccsinstitute.com/why-ccs/what-is-ccs/storage/>)

siting flexibility and rapid scalability. In the near term, the ability to deliver carbon in utilizable form for other value-added applications—potential examples include concrete production, synthetic fuels, and enhanced oil recovery—can help open up pathways to the successful commercialization of DAC technology.

- **DAC can help catalyze broader support for action to limit climate change.** By changing public and policymaker perceptions about the range of options to address climate change that are technically and economically feasible, progress on DAC and other CDR technologies can help shift the current political debate around climate change, catalyzing greater policy ambition and unlocking new investment to tackle the problem.

Put simply, we have reached a point in our collective understanding of the urgency of addressing climate change where all options that could make a meaningful contribution, and particularly those options that do not come with large downside risks of their own, must be on the table. DAC merits serious attention because of the specific advantages it offers and the climate benefits it can provide as part of a broader strategy that includes both policies to avoid and reduce anthropogenic greenhouse gas emissions and efforts to boost natural CO<sub>2</sub> removal processes. The remainder of this issue brief explores these arguments in greater detail.

## Direct Air Capture: Technology Basics and Policy Debate

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A variety of DAC systems have been proposed and, as of February 2020, seven small operating DAC facilities have been constructed or are under construction in the United States, Canada, and Europe.<sup>2</sup> All of these systems use fans to move large quantities of air through a filter or a liquid, which contains chemicals that bind to the CO<sub>2</sub>. In some designs, the CO<sub>2</sub> is first turned into a solid that will release pure CO<sub>2</sub> gas when heated; in other designs the filter or sorbent is directly heated to produce a concentrated stream of CO<sub>2</sub>. Because of these steps, DAC systems require energy to

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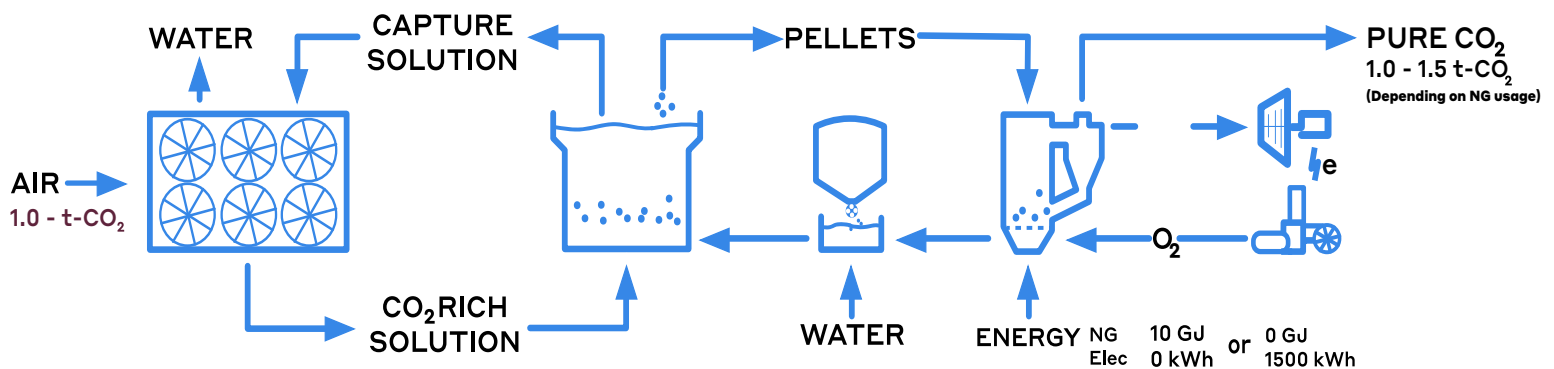
2 The three companies currently active in DAC are U.S.-based Global Thermostat, with pilot plants in California and Alabama, a commercial demonstration plant under construction in Oklahoma, and a technology center in Colorado; Canada-based Carbon Engineering, with a pilot plant in British Columbia; and Switzerland-based Climeworks, with plants in Iceland, Switzerland, and Italy. (See BPC Fact Sheets. Available at: <https://bipartisanpolicy.org/report/explaining-direct-air-capture/>)



operate; depending on the specific design, they typically also require inputs of chemicals and water.

Economic estimates for DAC have varied widely, with the costs of early systems over a decade ago estimated to be as high as \$600 per ton of CO<sub>2</sub> captured; however, as the technology has continued to advance in development and as DAC systems have been more closely analyzed by independent experts, including recently by the National Academy of Sciences, current estimates suggest that removal costs could be in the \$100-\$200 range, or possibly lower over time as the technology scales.<sup>i</sup> Key issues, from both an environmental benefit and economic cost/viability standpoint, include how the energy needed to power DAC systems is sourced, and whether the captured CO<sub>2</sub> provides value—either because climate policies have created a market for carbon reductions or because commercial applications exist to use (and pay for) the captured CO<sub>2</sub>. These issues are discussed in more detail in a separate issue brief by the Advisory Council, which focuses on the business case for DAC, and in a later section of this brief, which looks specifically at using captured CO<sub>2</sub> in enhanced oil recovery.

**Figure 1. Schematic of a DAC Liquid Solvent System**



Source: Akshat Rathi. "Our Technology." carbonengineering.com. Available at: <https://carbonengineering.com/our-technology/>

Although the idea of DAC has been around for some time, its technical and economic feasibility and, more importantly, its policy merits have been strongly contested until fairly recently. A central concern has been "moral hazard": the possibility that focusing on CDR would distract from, and could even undermine, efforts to reduce and avoid emitting CO<sub>2</sub> and other greenhouse gases in the first place. According to this view, the mere

possibility that a future technology could be used to remove CO<sub>2</sub> emissions after the fact might serve as an excuse to continue locking in long-lived fossil fuel technologies and infrastructure, and divert resources from more immediate, less costly, and more certain mitigation opportunities.

As we discuss in the next section, the context for these policy and technology debates, and for attendant moral hazard concerns, has shifted dramatically. With growing awareness of how quickly time is running out to limit the pace and magnitude of warming this century, environmental advocates, investors, and policymakers are looking more closely at a suite of CDR strategies, including DAC.

## The Environmental Imperative for an “All of the Above” Approach

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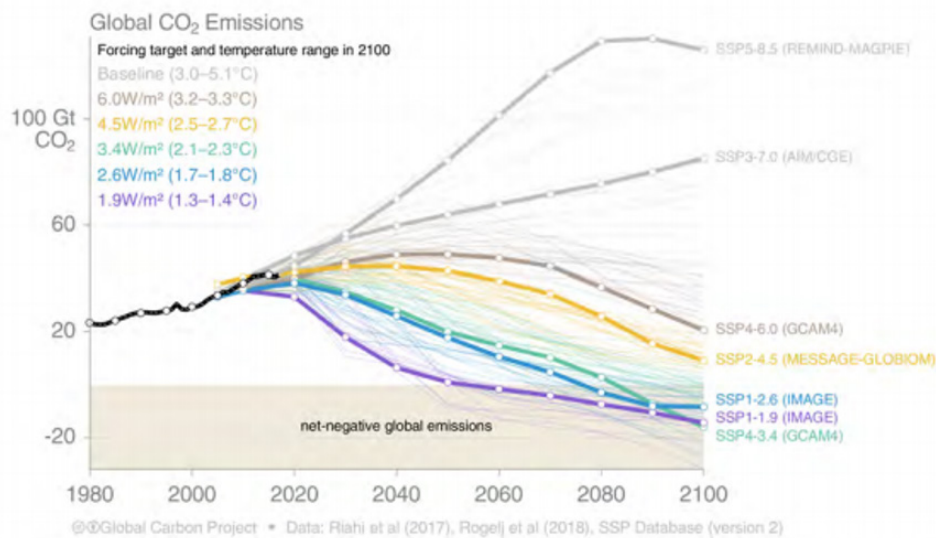
Throughout 2019, news headlines seemed to bear out the conclusion of a recent United Nations synthesis report on climate change: “There is a growing recognition that climate impacts are hitting harder and sooner than climate assessments indicated even a decade ago.”<sup>ii</sup> In a year that broke records around the world for extreme heat, flooding, ice melt, and catastrophic wildfires, the public and the business community also seemed to be paying new attention. Early in 2020, participants at the World Economic Forum in Davos, Switzerland listed climate change as their top priority for the first time, and several major multi-national corporations announced new plans to cut emissions and change their investment strategies to favor climate-friendly technologies.<sup>iii</sup>

Yet 2019 was also a year that brought the widening gap between rhetoric and action on climate change into sharper focus. Though most of the world’s nations remain nominally committed to the Paris Agreement’s goal of limiting future warming to less than 2°C above pre-industrial levels, actual policy commitments continue to fall far short of reflecting this goal. According to the same UN synthesis report cited above, the policy ambition reflected in current “Nationally Determined Contributions” under the Paris Agreement would have to be roughly tripled to be in line with the 2°C goal; to limit warming to a more conservative 1.5°C, which many scientists warn is needed to avoid large-scale climate damages, current commitments would

have to increase fivefold.<sup>iv</sup>

To achieve either goal, in fact, global greenhouse gas emissions need to begin declining now and reach net-zero by mid-century. Figure 2 shows emissions trajectories consistent with different warming targets, based on the latest international modeling analyses. As is evident from the figure, tools to remove atmospheric CO<sub>2</sub> will become important if these targets are to be realized.<sup>3</sup>

**Figure 2. CO<sub>2</sub> Trajectories for Different Warming Targets**



Source: “Key Messages.” United in Science. High-level synthesis report of latest climate science information convened by the Science Advisory Group of the UN Climate Action Summit 2019. Contributing organizations: World Meteorological Organization, United Nations Environment, Intergovernmental Panel on Climate Change, Global Carbon Project, Future Earth, Earth League, and the Global Framework for Climate Services. Sept. 22, 2019. Available at: [https://public.wmo.int/en/resources/united\\_in\\_science](https://public.wmo.int/en/resources/united_in_science)

Far from showing signs of peaking, however, global CO<sub>2</sub> emissions over the last decade have continued to grow, at a rate of roughly 1% per year on average after a brief dip as a result of the Great Recession. In 2018, global energy-related CO<sub>2</sub> emissions increased by 2%, reaching a new high of 37 billion metric tons.<sup>4</sup> Emissions data for 2019 are not yet available, but the Global Carbon Project has estimated that global emissions grew 0.6% from

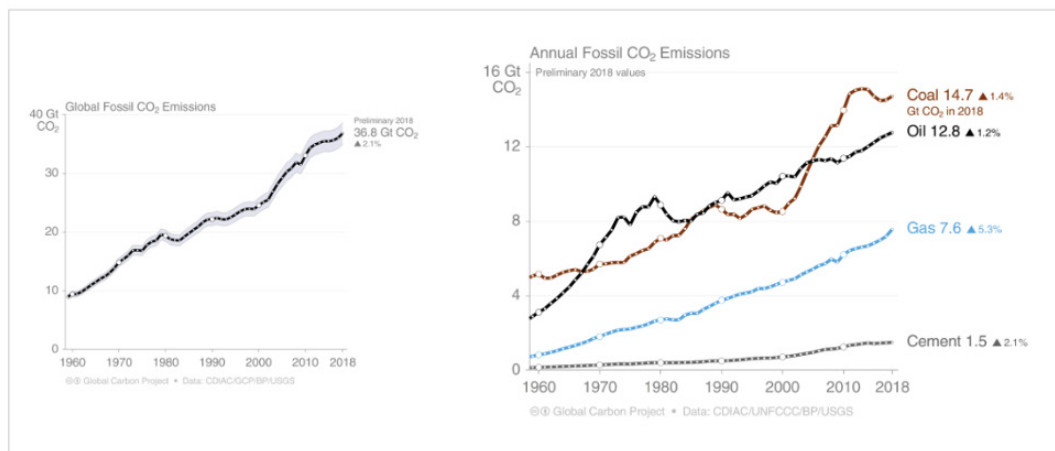
<sup>3</sup> In particular, the chart shows that achieving either a 1.5°C or 2°C target for limiting warming would require net-zero emissions by approximately mid-century and some level of negative emissions before 2100. The more conservative 1.5°C target requires a steeper initial emissions reduction and carbon removal trajectory.

<sup>4</sup> Emissions of all major anthropogenic greenhouse gases grew 1.6% per year on average from 2008 to 2017 and totaled an estimated 53.5 billion metric tons CO<sub>2</sub>-equivalent in 2017. (See United in Science report. Available at: [https://public.wmo.int/en/resources/united\\_in\\_science](https://public.wmo.int/en/resources/united_in_science))



2018 to 2019. Analysts have found that most countries are not on track to meet even the initial commitments they made under the Paris Agreement.<sup>v</sup> Meanwhile, although coal use is declining in some regions, including in the United States, global coal consumption continues to increase and governments and businesses around the world have continued to make large capital investments—to the tune of nearly \$1 trillion in 2018 alone—in long-lived fossil-fuel infrastructure, from pipelines and coal mines to refineries and conventional power plants.<sup>vi</sup>

**Figure 3. Trends in Energy-Related CO<sub>2</sub> Emissions**



Source: “Key Messages.” United in Science. High-level synthesis report of latest climate science information convened by the Science Advisory Group of the UN Climate Action Summit 2019. Contributing organizations: World Meteorological Organization, United Nations Environment, Intergovernmental Panel on Climate Change, Global Carbon Project, Future Earth, Earth League, and the Global Framework for Climate Services. Sept. 22, 2019. Available at: [https://ane4bf-datapl.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/United\\_in\\_Science\\_ReportFINAL\\_0.pdf?XqiGOyszsUsx2vOehOWpCOKm9RdC\\_gN](https://ane4bf-datapl.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/United_in_Science_ReportFINAL_0.pdf?XqiGOyszsUsx2vOehOWpCOKm9RdC_gN)

Faced with these realities, it is increasingly clear that focusing on any single mitigation strategy, policy approach, or category of technologies will not suffice. Action is needed on multiple fronts—to aggressively implement those emission reduction opportunities that are already available and cost-effective and transition to lower-carbon energy sources without delay, but also to develop and commercialize new technologies that could deliver deeper reductions—and eventually net negative emissions—later this century. The need for such technologies, and the specific attributes that argue for further investment to advance DAC in particular, are the subject of the next sections.

# Carbon Dioxide Removal as a Complement to a Comprehensive Climate Mitigation Strategy

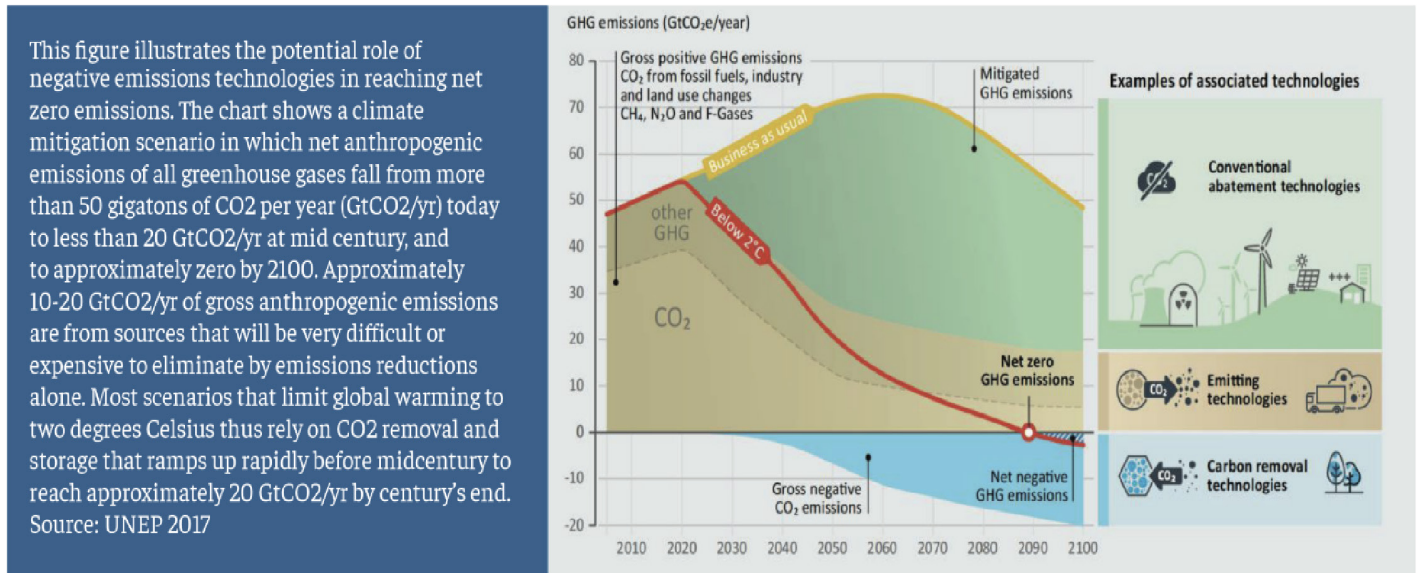
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With global anthropogenic greenhouse gas emissions still rising, the practical difficulty of meeting international climate targets is hard to overstate. Achieving net-zero emissions within a mid-century timeframe will be extremely challenging, even in sectors—such as electricity production—where commercially competitive zero-carbon alternatives already exist. In other energy-use sectors, such as long-haul air travel and marine shipping, new fuel technologies, such as hydrogen, hold promise but are likely to remain prohibitively expensive for some time to come. And many of these hard-to-decarbonize emissions sources cannot make use of the kind of carbon capture and storage technology that has been proposed for large point sources of CO<sub>2</sub> such as coal and natural gas-fired power plants or large industrial facilities. Adding to the overall challenge of getting to net-zero are the various non-energy-related sources that also produce greenhouse gases, from industrial processes that generate CO<sub>2</sub> as a direct by-product of chemical reactions, to land-use practices and agricultural sources that produce methane and CO<sub>2</sub>. Meanwhile, climate change itself has the potential to boost natural sources of greenhouse gases, for example by causing large releases of methane from thawing permafrost or by contributing to persistent forest dieback as a result of wildfires and drought.

For these reasons, several expert organizations have concluded that active CDR strategies—sometimes called negative emissions technologies or NETs—will be essential to limit warming this century and perhaps beyond. According to the UN synthesis report cited previously: “Meeting the Paris Agreement requires immediate and all-inclusive action encompassing deep decarbonization complemented by ambitious policy measures, protection and enhancement of carbon sinks and biodiversity, and *efforts to remove CO<sub>2</sub> from the atmosphere*.”<sup>vii</sup> A 2018 special report by the Intergovernmental Panel on Climate Change (IPCC) noted that all modeled pathways for limiting warming to 1.5°C project the use of CDR.<sup>viii</sup> Similarly, the NAS has concluded that negative emissions technologies will need to play “a significant role,” for the simple reason that deploying such technologies “may be less expensive and less disruptive than reducing some emissions,

such as a substantial portion of agricultural and land-use emissions and some transportation emissions.”<sup>ix</sup>

**Figure 4. The Role of CDR (or “Negative Emissions Technologies”) in Climate Mitigation**



Source: National Academies of Sciences, Engineering, and Medicine. Negative Emissions Technologies and Reliable Sequestration. Consensus Study Report. Highlights. Oct. 2018. Available at: <https://www.nap.edu/resource/25259/Negative%20Emissions%20Technologies.pdf>

DAC, as we have already noted, is only one of a number of “negative emissions” or CO<sub>2</sub> removal strategies that could be used to help mitigate warming over the next century. Others include measures to increase forest biomass (e.g., afforestation and reforestation), measures to increase soil carbon sequestration (e.g., land restoration and changes in agricultural practices), bioenergy with carbon capture and storage, enhanced weathering to promote carbon mineralization (essentially, exposing reactive minerals in rock to bind with CO<sub>2</sub> in the atmosphere), and ocean alkalization.<sup>x</sup> These options, as the IPCC has pointed out, “differ widely in terms of maturity, potentials, costs, risks, co-benefits and trade-offs.”<sup>xi</sup> The specific advantages of DAC, and the reasons why it might be needed in addition to biological or land-based CDR strategies such as afforestation, are the subject of the next section.

# The Unique Potential of Direct Air Capture

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Of the strategies available to meet the 2°C target for limiting warming, forestry and land-based approaches are widely considered the most cost-effective and readily deployable in the near term. However, they will likely not be enough. The NAS, for example, has estimated that a combination of forestry, agriculture, and land-use based measures, together with substantial deployment of bioenergy with carbon capture and storage, could theoretically produce as much as 10 billion metric tons of CO<sub>2</sub> removal per year—roughly half the 20-billion-ton requirement already noted.<sup>xii</sup> But achieving this potential would require “unprecedented rates of adoption of agricultural soil conservation practices, forestry management practices, and waste biomass capture.”<sup>xiii</sup> As a result, the realistic potential for biomass and land-based measures is likely to be substantially lower, perhaps on the order of half the theoretical potential. According to the NAS: “[T]hese existing options cannot provide the amount of negative emissions needed to meet climate goals without unprecedented changes in land use that could affect food availability and biodiversity.”<sup>xiv</sup>

As a candidate to provide additional, large-scale CO<sub>2</sub> removal capability, DAC offers important advantages—particularly with respect to scalability, siting flexibility, and permanence. DAC plants can be large or small, and because they rely on industrial processes (rather than on biological mechanisms like photosynthesis), they can be controlled and adjusted as needed. DAC capacity can also be added in increments, using modular systems, which allows for flexible expansion as the need or opportunity arises. DAC systems make it possible to place captured CO<sub>2</sub> permanently in the geosphere. By contrast, natural carbon storage strategies take a different path and sequester the carbon in the biosphere, which can present permanence challenges (e.g., if forests burn). And finally, DAC systems can be located in a range of geographic settings, thereby avoiding competition with other land uses; unlike carbon capture and storage systems that capture CO<sub>2</sub> from more concentrated exhaust gas streams, they need not be co-located with major emissions sources.<sup>5</sup>

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5 Because carbon capture and storage (CCS) can be used to avoid new emissions, but not to remove CO<sub>2</sub> from the ambient air, it is considered a zero-carbon technology, but not a negative emissions technology.

A recent modeling assessment put the potential for CO<sub>2</sub> removal and storage using DAC at 16–30 billion metric tons per year in the 2070–2100 timeframe under different deep decarbonization scenarios and economic and technical assumptions. The study authors found that deploying DAC “significantly reduces mitigation costs” and “complements rather than substitutes other NETs.” The authors also concluded that the key factor limiting DAC deployment is the rate at which the technology can be scaled up.<sup>xv</sup>

An important design issue for DAC systems—in terms of both cost and environmental impact—is energy use. DAC systems will require energy inputs because the low concentration of CO<sub>2</sub> in ambient air means that large volumes of air have to be moved through DAC systems to capture appreciable quantities of CO<sub>2</sub>. Depending on the specific capture process used, DAC installations may also require relatively low levels of thermal energy (85°C–120°C) or a much higher-temperature heat source (>800°C), in addition to electrical energy. Fortunately, siting flexibility makes it possible to locate DAC systems where low-cost and preferably low- or zero-carbon energy sources are available (e.g., waste heat or renewable energy). Siting flexibility also means that DAC plants can be located in settings that are favorable for the permanent geological storage of captured CO<sub>2</sub> (e.g., atop saline aquifers) or where commercial opportunities exist to use the CO<sub>2</sub>.

Such commercial opportunities are particularly important in contexts where governments have not taken policy action to create financial incentives for CO<sub>2</sub> reductions. In the United States, the federal government currently provides a tax credit, known as 45Q, to encourage geologic storage of CO<sub>2</sub>; more recently the state of California added DAC with geologic CO<sub>2</sub> storage to the technologies that can qualify for a credit under its low-carbon fuel standard. Congress extended the 45Q tax credit to DAC in 2018, but the Internal Revenue Service has been slow to issue a final rule on the updated 45Q tax credit.

While the 45Q tax credit is expected to have an impact in terms of incentivizing DAC, finding other commercial opportunities for captured CO<sub>2</sub> remains important as a way to bridge the proverbial “valley of death” between lab-bench research to demonstration-size projects and successful commercial-scale technology deployment. One particularly promising possibility for navigating this critical transition in the case of DAC involves enhanced oil recovery in the petroleum industry. EOR refers to a variety of techniques for recovering additional oil from mature wells, after primary and secondary extraction has taken place, typically through the forceful injection of a liquid or gas to flush remaining oil to the surface and cause



the oil to flow more readily. After the process is complete, the well is sealed, leaving the injected liquid or gas underground. CO<sub>2</sub> is already widely used in EOR applications, but typical industry practice has been to pump CO<sub>2</sub> from natural underground reservoirs, which provides no climate benefit. If the CO<sub>2</sub> is instead captured from the atmosphere, however, EOR provides a pathway for achieving a significantly lower carbon footprint from oil. To test this concept, Oxy Low Carbon Ventures, a subsidiary of Occidental Petroleum, has announced plans to use Carbon Engineering's DAC technology to produce CO<sub>2</sub> for EOR operations in Texas.<sup>xvi</sup>

Proposals to pair DAC with EOR have been controversial because of the apparent contradiction of using a climate-mitigation technology to boost fossil-fuel production.<sup>6</sup> But this approach has also drawn support from many experts, including some environmental advocates, who see EOR applications as offering the most viable near-term pathway to commercializing DAC technology and as a way to offset some of the negative climate impacts of oil use, which is bound to continue for some time, with or without EOR. A recent analysis by the World Resources Institute estimated that under one scenario EOR with DAC would reduce net CO<sub>2</sub> emissions by about one-third compared to conventional oil production.<sup>xvii</sup> The benefit could be more or less depending on multiple input assumptions, including the source of energy used for DAC and assumptions about how much of the oil extracted using EOR would have been produced anyway.<sup>7</sup>

## Conclusion

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According to the United Nations, average global temperatures over the period from 2015 to 2019 are on track to be the warmest of any equivalent period on record. In light of the current pace of decarbonization and the challenges inherent to reshaping the global energy economy, we believe an ambitious program to bring forward additional technologies that can support effective climate-change mitigation is clearly warranted.

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- 6 The concern is that EOR, by increasing the supply of economically recoverable oil and keeping oil prices lower than they otherwise would be, promotes continued use of a carbon-emitting fuel, which is counterproductive to climate mitigation.
  - 7 The International Energy Agency has estimated that for every ten barrels of oil produced using CO<sub>2</sub>-based EOR, eight barrels would have been produced anyway. (See International Energy Agency. Insights Series 2015. Storing CO<sub>2</sub> through Enhanced Oil Recovery: Combining EOR with CO<sub>2</sub> storage (EOR+) for profit. 2015. Available at [https://nachhaltigwirtschaften.at/resources/iea\\_pdf/reports/iea\\_ghg\\_storing\\_co2\\_trough\\_enhanced\\_oil\\_recovery.pdf](https://nachhaltigwirtschaften.at/resources/iea_pdf/reports/iea_ghg_storing_co2_trough_enhanced_oil_recovery.pdf))

Technologies like DAC are, as the NAS points out, currently “underexplored” but they could have “essentially unlimited capacity” if cost barriers and other unknowns can be overcome.<sup>xviii</sup> Those barriers and unknowns aren’t trivial, especially at the scale of deployment needed to make a meaningful contribution, but the payoffs—environmentally and economically—could be substantial. Meanwhile, the leadership opportunity for the United States in this domain shouldn’t be overlooked. By supporting vigorous RD&D efforts and by creating policy incentives for early commercial deployment, the U.S. government can help ensure that DAC costs come down and that U.S. companies have the intellectual property advantages and implementation experience to compete successfully in future global markets for this and other CDR technologies.

Of course, investments in any novel technology, whether by the government or by the private sector, rarely come with a guarantee of success. But betting that we won’t need DAC is risky too—and arguably even irresponsible given the track record of recent decades. The fact that DAC has relatively low downside risks, certainly compared to some other large-scale climate interventions, such as geoengineering, that might be considered if warming continues to accelerate, is a further argument for pursuing targeted efforts to advance DAC and other CDR strategies.

Put simply, we can no longer afford to adopt a “wait and see” or “if all else fails” approach to climate innovation. The sheer enormity of the challenge presents its own kind of moral hazard: a temptation to take half measures, or worse, to do nothing, as long as we think we lack adequate solutions. It can take decades for an innovative technology to achieve widescale deployment, so investment to advance promising new options is especially critical now—as a way to create and sustain momentum for decisive climate action in the crucial decades ahead, and as the only way to ensure that tools like DAC will be ready when we need them.

# Endnotes

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