International Efforts in Carbon Dioxide Removal: Soil Carbon and Direct Air Capture

Recommendations for Further US Action

December 2020

A Report Developed for Carbon180

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Cornell Global Climate Change Science and Policy Course
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Acknowledgements

We appreciate the support of Carbon180, the Department of Earth & Atmospheric Sciences, and the Department of Global Development at Cornell University for providing the impetus for, and support of this work. The authors would like to thank Vanessa Suarez, Natalie Mahowald, and Allison Chatrchyan for providing key insights and feedback on this research, as well as the students enrolled in EAS 4443: Global Climate Change Science & Policy for their consistent enthusiasm.
Executive Summary

By pledging to rejoin the 2015 Paris Climate Agreement on their first day in office and appointing a presidential envoy on climate, the new US presidential administration has signaled its intent to make climate change a top priority. While decisions are being made about where to allocate economic and political capital, the US has an opportunity to bolster the nascent carbon dioxide removal (CDR) technologies industry. CDR is increasingly seen as a vital instrument for reaching targets set forth by the Paris Agreement, and limiting warming of the global climate system.

Despite this growing awareness, CDR is rarely mentioned in international agreements and is often maligned in environmental circles due to its ties to the oil and gas industry as a means to forgo necessary deep emissions cuts. International efforts for research and implementation of direct air capture (DAC) and soil carbon technologies are limited. Doubts surrounding CDR, and especially DAC and soil carbon storage, are overstated and these technologies should be embraced by the international climate change mitigation community not as a substitute, but as a necessary addition to significant emissions cuts in mitigation pathways. DAC and soil carbon storage are carbon negative strategies that can transform the global fight to control atmospheric CO₂. However, at current prices for carbon, DAC is not cost effective and soil carbon storage is still in its earlier stages of development and execution.

This report surveys the landscape of the burgeoning DAC and soil carbon storage industry and recommends that the US do more to catalyze international cooperation for research and implementation of these technologies. Specifically, the US should: 1) convene an international working group with an annual research conference for scaling up DAC and soil carbon; 2) create a fund similar to the Green Climate Fund which focuses exclusively on CDR; 3) include DAC and soil carbon storage in their second NDC; and 4) expand it’s ARPA-E programs to include a CDR or DAC specific research funding opportunity. By following these recommendations, the US will become a leader in these new and growing markets and spur innovation toward a carbon negative future.
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# Acronyms

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<tr>
<td>BECCS</td>
<td>Bio-energy Carbon Capture and Storage</td>
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<tr>
<td>CCS</td>
<td>Carbon Capture and Storage</td>
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<td>CCUS</td>
<td>Carbon Capture Utilization and Storage</td>
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<td>CDR</td>
<td>Carbon Dioxide Removal</td>
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<td>DAC</td>
<td>Direct Air Capture</td>
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<td>ESG</td>
<td>Environmental Social Governance</td>
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<td>EU</td>
<td>The European Union</td>
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<td>GHGs</td>
<td>Greenhouse Gasses</td>
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<td>HVAC</td>
<td>Heating Ventilation and Air Conditioning</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>NDCs</td>
<td>Nationally Determined Contributions</td>
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<td>PPM</td>
<td>Parts Per Million</td>
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<td>SDGs</td>
<td>Sustainable Development Goals</td>
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<td>UN</td>
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Introduction

As the impending climate crisis advances, there is an increasing sense of urgency to scale up research and application of carbon dioxide removal (CDR) technologies. CDR is the process by which various engineered technologies and terrestrial processes remove carbon dioxide from the atmosphere to sequester it for long periods of time. CDR is an important way to offset the global greenhouse gas emissions that are occurring at increasingly alarming levels. In order to scale CDR efforts to a significant level, a better understanding of the international status of CDR solutions and avenues for further collaboration is necessary.

Today, it is clear that the goals of the Paris Agreement established in 2015 to keep global warming below 1.5 degrees Celsius within this century are unlikely to happen without the use of CDR. Although President Trump announced that the US would drop out of the Paris Agreement in 2017, the incoming Biden Administration has signaled it will rejoin on the first day of the new administration - and therefore, there is a strong need for the United States to collaborate with other countries in advancing research, technology, and policy to better fit the ambitious goals of the Agreement. The Paris Agreement itself does not lay out national quotas on CDR, but nevertheless, countries are working together to advance research and development of CDR technologies that will help achieve the goal of the Agreement. Core parts of the Paris Agreement, like the ambitious temperature goals and the discussion of a balance between emissions and removals, imply that CDR needs to be widely used and expanded. The new US administration has the opportunity to bring along knowledge, expertise, and advocacy for CDR solutions.

This report explores the current existence of CDR in global research agreements and subsequently notes opportunities for obtaining funding to expand these agreements and initiatives. It identifies ways for the US to get involved in these agreements and suggests
potential policy solutions to ramp up CDR internationally. Despite the vast number of international climate organizations and cooperative agreements, the international community is not yet on track to meet climate goals, as emissions are expected to continue to rise over the next several decades. For this reason, it is imperative that policy recommendations be made and all avenues for potential funding and expansion are exhausted. The new presidential administration has shown a sense of urgency toward climate change and it has the opportunity to bring CDR firmly into the global climate conversation.

Background

Current atmospheric carbon dioxide levels are the highest they have been for the past 650,000 years.\(^1\) Human activities such as the burning of fossil fuels have caused a 47% rise in atmospheric CO\(_2\) above pre-industrial levels - from 280ppm to over 400ppm in the last 170 years.\(^2\) That’s a greater increase in CO\(_2\) levels than occurred naturally for 20,000 years leading up to 1850.\(^3\) This anthropogenic increase in atmospheric CO\(_2\) along with other GHGs has already caused just over 1°C warming of average global temperature, most of which has occurred in the last 50 years, at a startling rate of 0.15-0.2°C per decade.\(^4,5\) Continuing down a “business as usual” path will lead to further warming of the global climate system by 3-5°C above pre-industrial levels by the end of this century.\(^6\)

This degree of global warming may not seem significant, but the IPCC 1.5 report warns of high risks to natural and human systems even if warming is limited to 1.5-2°C.\(^7\) These risks include increased extreme weather events, sea level rise, loss of unique/threatened ecosystems, drought and crop failure. Many of the worst impacts of climate change are projected fall on the poorest and most vulnerable populations.\(^8\)
In response to the ever-growing threat of human-caused global climate change, more than 185 countries have now ratified the 2015 Paris Agreement, with the central objectives of limiting the warming of the global climate system to 2°C above pre-industrial levels and to pursue efforts to further limit this warming to 1.5°C. To this end, each Party produced a NDC describing intended GHG emissions reductions targets, and measures and policies that will be implemented to reach those targets. Even if these commitments are upheld, there is a 90% chance that global temperatures warming will exceed 2°C above pre-industrial levels and a 50% chance to exceed 2.7°C warming above pre-industrial levels by the end of the century. Thus, these efforts at mitigation laid out by Party NDCs alone are not sufficient to meet the goals set out by the Paris Agreement.

All pathways to 1.5°C warming by 2100 projected by the IPCC are achievable only with drastic emissions reductions and implementation of large-scale CDR. CDR technologies remove CO\textsubscript{2} from the atmosphere and store it in geologic, terrestrial, and ocean sinks, or in products. Some CDR technologies enhance natural CO\textsubscript{2} capturing processes, while others are engineered technologies to draw CO\textsubscript{2} out of the atmosphere. Currently, the most common CDR techniques integrated into potential mitigation pathways are BECCS and afforestation/reforestation. The limiting factor for these two strategies is competition for enough land area to effectively employ these technologies at scale and in an equitable manner. Therefore, other CDR strategies should also be explored and implemented to draw down atmospheric CO\textsubscript{2}. The longer we wait to drastically reduce emissions, the more dependent we will become on CDR.

It is important to distinguish between CDR and CCS. CDR technologies remove CO\textsubscript{2} from the ambient atmosphere, whereas CCS captures CO\textsubscript{2} from point sources, such as power
plants.\textsuperscript{15} Thus, CCS technologies do not reduce atmospheric CO\textsubscript{2} levels, but rather prevent carbon emissions from being released into the atmosphere. These technologies have a long history with oil and gas companies, raising concerns over the perpetuation of fossil fuels, as well as the future funders and influencers of CDR deployment. While they may help in reducing further CO\textsubscript{2} additions to the atmosphere, they do not help to sequester historical emissions as CDR does. To best meet the goals of climate change mitigation targets, it is more important to focus on permanent removal of CO\textsubscript{2} through processes like DAC.

This report focuses on two CDR techniques, DAC and soil carbon storage. DAC or DACCS (direct air capture with carbon storage) is a technological carbon removal solution that sucks CO\textsubscript{2} directly out of the ambient air. There are three main tactics used to separate CO\textsubscript{2} from the ambient air.\textsuperscript{16} First, the chemical technique uses solid sorbents or liquid solvents to temporarily bind to the CO\textsubscript{2}. Then, low-CO\textsubscript{2} air is released and the captured CO\textsubscript{2} is extracted from the sorbent or solvent. Second, the cryogenic method separates CO\textsubscript{2} by freezing it out of the air. Finally, specific types of membranes can be used to separate CO\textsubscript{2} from the air.\textsuperscript{17} The most commonly used of these in DAC operations is the chemical separation method. Once the CO\textsubscript{2} is isolated from the ambient air, it can be stored permanently in geologic sinks or can be used in producing commercial products like cement. Unlike other CDR methods, DAC is not expected to use large amounts of land, so there are many locations suitable for DAC facilities.\textsuperscript{18} The main consideration for the location of DAC facilities is closeness to storage sites or utilization facilities, limiting the distance captured CO\textsubscript{2} must be shipped. The current challenges facing DAC technologies are energy and monetary cost. Current DAC costs range from $300-$600/tCO\textsubscript{2}, making it more expensive than many other CDR technologies.\textsuperscript{19} Because the concentration of CO\textsubscript{2} in ambient air (0.04\%) is much lower than point sources (5-12\%), it is much
more energy-intensive to extract CO$_2$ from ambient air.$^{20}$ High cost and energy consumption limit the scalability of current DAC technology, but with further research and development and financial incentives, this technology can provide an important CDR pathway in a wide variety of locations.

Soils store carbon through natural processes. What’s more, through certain land management practices and advanced technologies, we can enhance the carbon-storing abilities of soils. Soil carbon storage (or soil carbon sequestration) is a land-based carbon removal solution that involves changing land management strategies to increase the natural carbon sink in soils by increasing organic carbon. This results in a net removal of CO$_2$ from the atmosphere.$^{21}$ Land management strategies for increasing the carbon storage capacity of agricultural soils include conservation tillage, perennialization, cover cropping, double cropping, crop rotation, managed grazing, compost application, agroforestry, and biochar application.$^{22,23}$ Soil carbon storage represents a huge carbon removal opportunity; agricultural soils in the US have the capacity to sequester 10% of US emissions for as little as $10/\text{tCO}_2$.$^{25}$ SCS offers a low-cost CDR method which has large potential for expansion in developing nations, especially those with agrarian economies. However, one challenge facing soil carbon storage is that there are current challenges with measurement and verification of carbon captured in soils. It is not easy to ensure that these management practices are actually being used on the individual farm scale. Nevertheless, offering incentives for farmers to use these technologies, and devising policies to monitor implementation will make SCS a viable CDR technique, especially for countries which are agriculturally-oriented.
The following three sections focus on the international landscape of CDR research agreements and efforts, soil carbon organizations, and companies focused on DAC.

International Agreements and Foreign Efforts

Because of the challenges associated with DAC and other CDR technologies, there is a dire need for not only research and development, but also demonstration and deployment to make these technologies economically viable and scalable. International research agreements are vital to social justice, to collaborating on lessons learned, to agreeing upon best practices, and more. Also of importance is their capacity to help attain the funding necessary to do high-impact DAC research. This report explores a number of non-US based research agreements and organizations, some of which span national boundaries, that fund and carry out important climate change research and which have done, or are doing work on DAC and CDR. The successes and challenges of these agreements should serve as models for future US DAC research endeavors, and provide inspiration for ways the US can bolster its involvement in the international CDR research sphere.

Coupled Model Intercomparison Project Phase 6

The Carbon Dioxide Removal Model Intercomparison Project 27, 28

World Climate Research Programme29; Kiel Earth Institute 30

The Carbon Dioxide Removal Model Intercomparison Project (CDRMIP) is a research program founded by the Kiel Earth Institute in Germany. The project is endorsed as part of the Coupled Model Intercomparison Project Phase 6 (CMIP6) of the World Climate Research Programme (WCRP), which provides a platform for scientists from around the world to share
and compare their climate models. Projects within the WCRP’s CMIP6 set standards and protocols which ensure that results can be analyzed collectively, resulting in better climate projections. The CDRMIP is the only project within CMIP6 which focuses on the potential impacts of CDR on the climate system. The CDRMIP is an international effort with organizations from the US, China, the UK, Norway, and Canada on its steering committee.

The CDRMIP itself seeks to compare the impacts and efficacy of different CDR initiatives. CDRMIP combines models of the Earth system in a common framework to understand the impacts, potential, and challenges of CDR technologies. The project has two key areas it seeks to address: 1) Climate “reversibility”, the potential of CDR in efforts to return from future high levels of atmospheric CO\(_2\) to historic lower levels and 2) Potential efficacy, feedbacks, time scales, and side effects of different CDR methods including DAC, afforestation, and ocean alkalinization. The project does not currently have modeling projects which pertain to the potential impact of soil carbon storage CDR efforts. CDRMIP data is freely available upon registration.

**Moonshot Research & Development Program**

*Japan Science and Technology Agency (JST), New Energy and Industrial Technology Development Organization (NEDO)*

The Moonshot Research & Development Program, part of JST, supports high-impact, high-risk research. The program seeks to promote out-of-the-box type solutions to the world’s problems. One of the Moonshot goals is the “Realization of sustainable resource circulation to recover the global environment by 2050”. Research toward this goal is funded through NEDO. One of the program’s sub-goals is to advance technologies to sequester GHGs, particularly carbon dioxide, and convert them into usable materials. Pursuant with this goal, the Moonshot
R&D program has several overarching projects through which research proposals can acquire funding. There are two such projects which focus on DAC-specific research and one which focuses on agriculture-related CDR such as soil carbon storage.

The US has a similar agency for advancing research of nascent and visionary technologies called Advance Research Projects Agency-Energy (ARPA-E). Like the Moonshot R&D Program, ARPA-E funds high-risk, high-impact research into energy technologies which are not yet viable for private-sector investment. ARPA-E funds research under its 65 different established program areas as well as Special Projects which do not fall within these fixed categories, but are innovative and unconventional in nature. Additionally, every few years, ARPA-E will issue and “OPEN” Funding Opportunity Announcement (FOA) to catalyze research breakthroughs across the broad spectrum of revolutionary, but risky areas. The Rhizosphere Observations Optimizing Terrestrial Sequestration (ROOTS) program focuses on research to improve soil carbon uptake to increase crop productivity and sequester carbon. While ARPA-E does have the Innovative Materials and Processes for Advanced Carbon Capture Technologies (IMPACCT) and FLExible Carbon Capture and Storage (FLECCS) programs, both focus on CCS technologies and do not include DAC research. With that being said, ARPA-E has funded two DAC-related research projects; one through their Special Projects program, and one through their 2018 OPEN FOA. ARPA-E has yet to establish a program to focus on CDR in general, or DAC specifically.
European Institute on Economics and the Environment

*Euro-Mediterranean Center on Climate Change (Italy); Resources for the Future (Washington, DC)*\(^{33, 34}\)

The European Institute on Economics and the Environment (EIEE) is a collaboration between the Euro-Mediterranean Center on Climate Change and Resources for the Future to support environmental and economic research. EIEE funds economic research projects throughout Europe, the US, and internationally. Many EIEE projects focus on energy, natural resources, and environmental policy, with a significant emphasis on climate change. EIEE climate projects center around different energy policies and mitigation scenarios. While EIEE does not have projects specifically dedicated to DAC or CDR, it has supported research modeling the role of DAC in deep mitigation pathways, comparing its role in 1.5°C and 2°C, a project undertaken by US and European based organizations.

Innovation for Cool Earth Forum

*Japanese Ministry of Economy, Trade, and Industry (METI), New Energy and Industrial Technology Development Organization (NEDO)*\(^{35, 36, 37}\)

The Innovation for Cool Earth Forum (ICEF) is an annual conference hosted by the Government of Japan since 2014. ICEF brings together scientists, policymakers, and members of industry from across the globe to evaluate technological innovations to tackle climate change. Led by an international steering committee, ICEF is truly a global effort to foster communication and collaboration of innovative research ideas for addressing the climate crisis. As a culmination of the conference each year, contributors collaborate to create a roadmap for the future of research and policy for different climate-related technologies. The 2017 roadmap focused on carbon dioxide utilization. Though the roadmap focuses on utilization technologies associated
with CCS, these technologies are still relevant and useful for CO\textsubscript{2} captured through DAC. In 2018, ICEF produced a roadmap for DAC which outlines areas for expanding research to make DAC cost-effective and scalable, and policy recommendations to incentivize the use of DAC.

The following are major international agreements which do not specifically mention DAC but are otherwise worth describing as potential frameworks for future DAC and soil carbon research and investment agreements. The appendix also lists several other CCS centered research agreements that do not mention DAC or soil carbon sequestration.

**Green Climate Fund and Climate Investment Funds**

*Seoul Korea | Washington, DC US*

The Green Climate fund, the Climate Investment Funds, and to a lesser extent The Global Environment Facility and the Adaptation Fund, were all founded in recent decades to create blended finance mechanisms for climate change related projects in less developed nations. Blended finance is typically defined as an investment that is funded by private for-profit, philanthropic, and public entities. These funds use public money to leverage capital from private financial institutions and philanthropies through a mechanism called catalytic first loss capital. This lowers the investment risk to financial institutions because the public funding will be used to pay back the other investors in the case that the deal falls through.\textsuperscript{38} The Green Climate fund has raised 23.2 billion since 2010 and the Climate Investment Funds have leveraged 8 billion in public funding to create 53 billion in co-financing from other institutions.\textsuperscript{39} Despite all of this money, none of the four funds have any mention of DAC and predominantly mention CDR in reference to afforestation and preventing deforestation.\textsuperscript{40}
2015 Paris Climate Agreement

*International*

Of the 188 initial NDCs submitted before the Paris Agreement, only three mention CCUS at all. The three countries, Norway, Saudi Arabia, and Canada are major oil producers and mention CCUS as a way to lower the carbon emissions from their oil production. Saudi Arabia specifically mentions using the carbon captured for enhanced oil recovery to extract more oil. No NDC mentions DAC and while many allude to natural carbon sinks, soil carbon storage is also not explored to its potential. Signatories of the Paris agreement are required to submit a second NDC by 2020, but only three have so far.
Soil Carbon Initiatives

Agriculture-related carbon removal is already a highly sought-after process in a number of countries. Organizations have created a variety of technologies and techniques to accelerate the absorption of carbon into soils and turn biomass into biochar to lock carbon into a stable form that will remain out of the air for potentially thousands of years. Biochar is a charcoal-like substance that safely stores carbon, formed from organic material such as agricultural and forestry wastes. It has massive potential to aid in carbon sequestration and is already starting to be incorporated into international discussion about carbon removal. While a few conferences already take place to facilitate further research and development of agriculture-related carbon removal and soil carbon absorption technology, more will be needed in order to establish concrete policies regarding widespread implementation. Below are several organizations working on various aspects of agriculture-related carbon removal that both Carbon180 and the US government could potentially benefit from getting involved in.

Indigo Carbon

One particularly important company in the field of agriculture and carbon removal is Indigo Carbon, based in Boston, Massachusetts. In general, this organization works alongside farmers and focuses on developing technologies to improve environmental sustainability. Of particular interest to carbon dioxide removal techniques that Carbon180 specializes in is the Terraton Challenge, an initiative that persuades innovative companies to come up with methods of increasing the absorption of atmospheric carbon dioxide into agricultural soils. The three focuses of the challenge are finding methods to quantify soil carbon, developing technology to accelerate soil carbon sequestration, and coming up with financial incentives for growers who
capture soil carbon. This system of incentives has the potential to speed up carbon sequestration significantly. The global research network that Indigo Carbon has fostered is also of potential interest to Carbon180. Indigo Carbon partners with farmers around the world to enhance research that will improve environmental sustainability and accelerate innovation for growers worldwide. The research program operates in the United States and Argentina, conducting a variety of research projects including, but not limited to, soil mapping technologies, testing sensors, and new agronomic practices. Among other sectors, the agricultural sector has great potential to become a net sequesterer of carbon dioxide, and partnering with research organizations such as Indigo Carbon can facilitate progress in the field of carbon dioxide removal not just on the national scope, but in the international community as well.

**Carbon Cycle Institute**

The Carbon Cycle Institute is a nonprofit organization furthering the research and development of carbon farming techniques that aid in carbon sequestration. Based in California, the organization helps with applied research and policy advocacy for what’s called the Marin Carbon Project. This project found ways to increase rates of soil carbon sequestration through the use of compost as a rangeland soil amendment. In terms of climate education, they launched the Carbon Cycle 1.0 education strategy to increase carbon cycle literacy among decision makers and leaders in the field of climate change.

**4 Per 1000 Initiative**

Launched by France in December of 2015, the 4 Per 1000 Initiative aims to gain global commitments to demonstrate the important role that agriculture and soil carbon can play in
combating climate change and tackling food insecurity.\textsuperscript{45} In addition to their research-backed advocacy, the 4 per 1000 initiatives aims to increase soil carbon storage by 0.4\% every year to mitigate while simultaneously increasing food security. The initiative proves to be a prime example of how soil carbon sequestration has the power to reduce emissions while addressing social and climate inequities, including but not limited to increasing food security and providing jobs. In order for the global climate goals to be met, soil carbon must be incorporated into the policy agenda of the United States. For an initiative like this to work, there must be collaboration between scientists, corporations, and policymakers alike—and while France has already begun the process, the US should certainly follow in their tracks.

Carbon180, Indigo Carbon, the Carbon Cycle Institute, and the 4 Per 1000 Program are just three of many organizations/initiatives whose work is tangibly changing the way we think about carbon in the scope of climate change mitigation and adaptation and how we can sequester it to meet the hefty goals of the Paris Agreement. Encouraging an ongoing discussion and effort to further the sector of agriculture-related carbon removal has the potential to greatly expand carbon dioxide removal technologies and the overall discussions about it. Furthermore, collaboration between these organizations and others can help increase the scope of the discussion and ultimately inform policy decisions both domestically and internationally.
Direct Air Capture

As discussed in the background section of this report, DAC is an integral part of any climate change mitigation effort. However, at around $500/tCO₂, it is currently not a cost-effective way of removing CO₂.⁴⁶ The concentrated CO₂ that comes from the process is simply too expensive to be utilized in a way that can compete with traditional manufacturing processes. This relatively nascent technology must be buoyed by government and international research agreements to reach economies of scale. With help from governments, green technology minded start-ups, and research organizations, dozens of companies have sprung up in recent years to find solutions to these problems.

The following are innovative organizations working on DAC technology on an international scale. These organizations are spearheading best practices which are on the cutting edge of DAC and demonstrate that this technology can be scaled up to meet global demand for carbon removal.

Climeworks

_Zurich, Switzerland_

Based out of Zurich and founded in 2009, Climeworks is one of the world’s foremost organizations in DAC. The for-profit company has designed, built, and sold DAC systems across Europe. Currently, there are fifteen Climeworks machines actively removing carbon from ambient air across Europe. Their modular machines work off of renewable energy and each can remove 50 tons of carbon dioxide per year. They work best in tandem with one another and, due to their modular nature, can be easily scaled to any desired size.
In a recent project in Iceland, Climeworks has worked with Carbfix, a sequestration company, to safely store the carbon that they capture permanently in the earth. There are also many ways to use the captured carbon that prevent it from returning to the atmosphere. Climeworks has partnered with several utilization companies who make products from the raw CO₂ that they remove from the atmosphere.

In June, 2020 Climeworks announced that it had raised an additional 75 million USD, bringing the total raised to 125 million over the course of their existence. Currently, their funding model comes from individual subscribers looking to offset their carbon footprint or from businesses who have targeted net zero or net negative carbon goals. Notable corporate partners include Stripe, Accenture, and Audi.

**Soletair Power**

*Lappeenranta, Finland*

Soletair Power is a small Finnish start-up working on capturing CO₂ from inside buildings. They use DAC technology to remove indoor CO₂ from office spaces and large buildings where many people work. Claiming that CO₂ reduces cognitive functions, Soletair Power aims to increase workplace productivity and capture CO₂ at the same time. With seed capital from well known Swedish ESG firm Wartsila, the company is on its way to marketability.

The system works by placing a DAC machine on the roof of an office building. As the HVAC system for the building sucks in ambient air, Soletair’s machine removes the CO₂ and pumps it into the building. Soletair’s system will then use the captured CO₂ and create fuel on site. They say that the workers in the building will then be able to use that fuel for transportation to and from the workplace, creating a carbon-neutral fuel source.
Carbon Engineering

Squamish, Canada

Founded in Canada in 2009, Carbon Engineering is one of the pioneers in DAC. Along with Climeworks in Switzerland, Carbon Engineering is actively capturing CO$_2$ from ambient air. Their technology is generally large scale rather than modular. The company claims that at large scale, it can capture a ton of CO$_2$ for $100$ USD today. Their goal is to build a plant that can capture one million tons of carbon dioxide per year.

Similar to Soletair, Carbon Engineering is piloting an *air to fuel* model where the captured CO$_2$ is converted into synthetic crude oil for use in industry and transportation. These carbon-neutral fuels can then be used in difficult to decarbonize sectors like aviation and long haul shipping. In addition to their *air to fuel* business model, Carbon Engineering is working on the more traditional carbon sequestration or storage technologies as well. When powered by clean energy, these technologies are carbon negative. The firm’s business model is to meet corporations carbon neutrality and carbon negative targets by providing them with a reliable and cost-effective way of removing carbon permanently. To that end, Carbon Engineering recently partnered with Occidental Petroleum, and its $23$ billion USD in annual revenue, to open its first DAC facility by 2025. This move is part of Occidental Petroleum’s transition from being an oil and gas company to a “carbon management” company.\textsuperscript{52} Occidenta’s transition signals huge room for growth in DAC and CDR in general.
Conclusions

International cooperation is an integral part of the fight against climate change. Sharing of technology and best practices will be crucial to limiting the worst effects of climate change. The majority of the world came together in 1992, 1996 and 2015 to create the UNFCCC, sign the Kyoto Protocol, and the Paris Agreement. These agreements are evidence that the world knows that it must work together to solve this issue. The United States has, so far, been absent in many international research agreements. Despite the very effective negotiation tactics of the US and the skill of their diplomats to create these agreements, the US failed to ratify the Kyoto protocol and has recently left the Paris Agreement. Yet, the world continues to fight together against climate change without the full participation of the US. This report demonstrates that other countries, international organizations, and corporations are working together without the US to find solutions to the climate crisis. It is time for the United States to join them.

The fields of soil carbon and DAC are burgeoning around the world. Strong commitments to reduce carbon emissions from the EU, Japan, and China have led to increased funding and technological cooperation for these nascent technologies and practices. Despite that, DAC technology and soil carbon practices have not yet reached economic viability. The US has recently made significant strides in advancing these technologies, including a recent Department of Energy DAC research grant totaling 13.5 million dollars. Nevertheless, by failing to cooperate internationally, the US is falling short in utilizing the best practices of the industry. As the world’s largest economy, with a highly skilled workforce, the US has a great opportunity to take these examples and use its enormous economic and technological capacities to push them from interesting ideas to key parts of every nation’s climate mitigation plan.
With an understanding of the importance of US leadership in scaling DAC technology and soil carbon practices, we recommend the following:

Findings and Recommendations

**Finding 1:** *Outside of fossil fuel centered point source CCS, international research agreements of CDR are limited.* There are several key organizations that coordinate and advocate for international research around CCS and CCUS, including the clean energy ministerial ACT-CCS. Organizations that focus solely on more climate friendly carbon removal solutions like DAC and soil carbon are less common. There is a room to pioneer international agreements around these technologies.

**Recommendation:** In order to create synergy in CDR research and applications, the United States should convene an international working group of global efforts in CDR. This working group should also include industry leaders from DAC companies and the agriculture sector to study the best applications of DAC and soil carbon practices and technologies to meet the challenges of climate change.

a) This working group should culminate in an annual CDR research conference similar to Japan’s ICEF to foster increased communication of CDR research, and bring together US-based and international CDR research organizations.

b) A separate conference should be held uniting domestic and international organizations focusing on research and development in soil carbon sequestration and Biochar utilization to help incorporate farmers into the carbon removal/sustainable farming landscape.
Finding 2: Successful UN based programs the Climate Investment Funds and Green Climate Fund do not mention or incorporate DAC. These programs have created billions of dollars of financing by providing catalytic first loss capital for renewable energy and climate change resiliency projects in developing countries. These types of projects decrease the risk of investing in emerging markets for private financial institutions and funnel much needed cash into areas that would otherwise be seen as unsafe investments. These funds have some projects that focus on soil carbon or other natural carbon removal techniques, but neither mentions DAC at all.

Recommendation: Drawing on the frameworks established by the Climate Investment Funds and the Green Climate Fund, the United States could create funding mechanisms for DAC and Soil Carbon projects in developing countries.

a) While the US and other developed states should provide the financial support for this fund, developing nations should have a leading role in evaluating and prioritizing projects.

b) The US and other developed countries should provide catalytic first loss capital for well vetted DAC and Soil Carbon projects in least developed countries.

Finding 3: While some oil producing countries have included CCUS in their NDCs, DAC is not mentioned at all. The US submitted its first NDC in 2016 and besides mentioning ambiguous carbon sinks and pools, did not include CDR in their NDC. Saudi Arabia mentions CCUS but only in relation to their oil production. Countries did not see DAC as a realistic option for reducing emissions when the Paris Agreement was signed in 2015 and that is reflected in their NDCs. As counties submit their second round of NDCs, which are intended to be more
ambitious than their first, CDR technologies have matured and taken on new importance as climate mitigation strategies.

**Recommendation:** In order to bolster confidence in the viability of CDR, the United States should incorporate CDR generally, and DAC and Soil Carbon specifically, into their second NDC.

a) In order to fully compensate for its historic emissions, the US should incorporate DAC and CDR into its second, more ambitious NDC.

b) The US should use its negotiation prowess at the UNFCCC to push harder for the incorporation of CDR in climate mitigation guidance and country specific NDCs.

**Finding 4:** *DAC is a relatively new technology that is not economically viable at the current price for carbon and experimental research is needed to bring costs down.* The US government has a robust research infrastructure which includes NASA, the US department of Energy, and ARPA-E. These organizations are currently focused on a multitude of projects with relatively disparate goals. Although there has been some funding for DAC, this research is not coordinated with international efforts and is likely insufficient to fully scale down the price of DAC.

**Recommendation:** The United States should add CDR and DAC specific research programs to the ARPA-E portfolio to catalyze research efforts important to improving the feasibility of these technologies at scale

a) Establishing these programs ensures that funding is allocated to DAC research and that proposals relating to CDR and DAC have specified priority rather than being considered “special projects”.

Endnotes


2NASA. (2020), op. cit.

3NASA. (2020), op. cit.


12IPCC. (2018), op. cit.

13IPCC. (2018), op. cit.

14IPCC. (2018), op. cit.


16Sandalow et al. (2018), op. cit.
17Sandalow et al. (2018), op. cit.

18Sandalow et al. (2018), op. cit.

19Sandalow et al. (2018), op. cit.

20Sandalow et al. (2018), op. cit.


26Sandalow et al. (2018), op. cit.


37 Sandalow et al. (2018), op. cit.


Appendix 1

Research agreements and Organizations focused on CCS

The following organizations are related to this report but do not mention DAC
Additional DAC and Soil Carbon Operations and Research

Please follow the link below to a living document which lists current DAC and soil carbon operations and research efforts. We have highlighted a few of these in this report, but the document offers a more comprehensive list of our findings.

https://docs.google.com/spreadsheets/d/1umW4zIilqQFYdV4ra2x_R_DD6LrOVuFZwhtvYkWz9UA/edit?usp=sharing