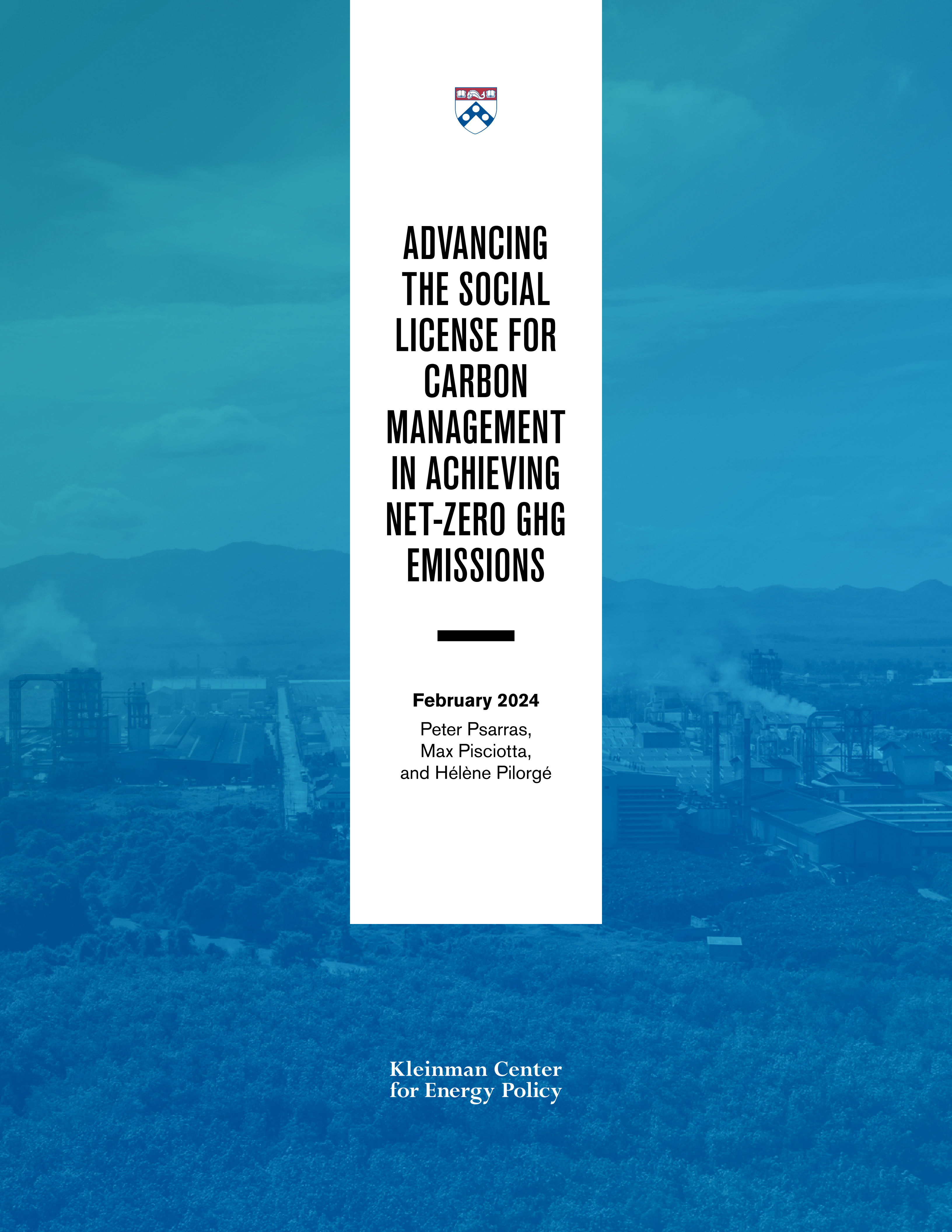

ADVANCING THE SOCIAL LICENSE FOR CARBON MANAGEMENT IN ACHIEVING NET-ZERO GHG EMISSIONS

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INTRODUCTION

In this policy digest, we argue that more clearly establishing the principled basis for carbon management would accelerate progress toward meeting net-zero greenhouse gas (GHG) goals.

The most likely way to ensure that carbon capture and storage (CCS) and carbon dioxide removal (CDR) play their necessary roles in meeting net zero is to explicitly define the limits of their roles and to establish mechanisms that ensure those limits are met.

As a basis for making progress on this topic, we also update readers on the current status of both carbon management technology and U.S. policies intended to support next-generation carbon management in the context of meeting net zero GHG emissions economy-wide.

THE NET-ZERO FRAMEWORK

The collective voice of climate science states unequivocally that to limit global warming to 1.5°C above pre-industrial levels will require both significant CO_2 emissions reductions, on the order of a 50% decrease compared to 2019 levels by 2030 to prevent temperature overshoot, and additional increases in CDR, on the order of billions of tonnes, or gigatonnes per year (Intergovernmental Panel On Climate Change (IPCC) 2023).

In 2022, Working Group III of the Intergovernmental Panel on Climate Change released the *Mitigation of Climate Change Report*, dedicating a section of Chapter 12 to CDR (IPCC 2022b). The top lines of the report's CDR *factsheet* states, "CDR is required to achieve global and national targets of net zero GHG emissions. CDR cannot substitute for immediate and deep emissions reductions, but it is part of all modeled scenarios that limit global warming to 2°C or lower by 2100" (IPCC 2022a) .

The report usefully summarizes the emerging policy design activity at various levels of governance around the globe:

> For countries with emissions targets aiming for net zero or lower, the core governance question is not whether CDR should be mobilized or not, but which CDR methods governments want to see deployed by whom, by when, at which volumes and in which ways. [...] CDR policymaking is faced with the need to consider method-specific timescales of CO_2 storage, as well as challenges in MRV [measurement, reporting, verification] and accounting, potential co-benefits, adverse side effects, interactions with adaptation and trade-offs with SDGs [Sustainable Development Goals] (IPCC 2022b) (*p1277*).

This helpful policy design agenda for CDR's role in achieving net-zero emissions identifies many of the elements that need to be converted into the arithmetic required for decision making and policy formulation. Foundational values are certainly present in the IPCC Report (for example, those aligned with the 17 sustainable development goals (SDGs) or those engendered by "co-benefits").

Yet, these values remain deeply obscured by the lack of a framework that defines methods for MRV and emissions accounting tied to timescales that articulate the relative durability among the various approaches to CDR.

We agree that the question of CDR (and carbon management more generally) should not take the form of "yes or no" but rather "under what conditions?" But we suggest that these conditions should be clarified into a compelling social license for carbon management as an urgent priority in the net-zero policy discussion. This license must stem from transparency and continue to earn credibility through rigorous system monitoring and responsiveness to stakeholders.

Today, confusion and distrust of how carbon management can best be leveraged for addressing climate change mitigation, are paralyzing policy design and slowing progress toward meeting our climate goals.

The confusion stems from many sources, including the vast, diverse, and growing space of CDR technologies; their variable maturities; and the continuous updates in their cost and deployment requirements. All of these realities generate a dangerously lagging understanding of CDR technology.

The distrust also stems from many sources. The history of unfettered private enterprise that has resulted in public harms in the United States cannot be ignored or perpetuated. From products ranging from tobacco to chemicals to automobiles to opioids to firearms, mis- and disinformation campaigns have been crafted to hide the public harms of these industries in the interest of profit.

Moreover, harm has concentrated in populations defined by location, occupation, and ethnicity. This history has generated a distrust of both government and private enterprise, which must be considered up front in all climate change strategies.

CDR also raises concern among some people about the "moral hazard"[1] created by a technology that could be used to preserve the incumbent asset value of prominent emitters or reduce pressure of other industries to transform their processes, rather than to pursue maximum effort on avoiding emissions. This is a bigger challenge with many CDR approaches than with carbon capture and storage (CCS) due to more complex emissions accounting.

It is a relatively straightforward policy design task to internalize CCS costs into the prices facing big emitters and consumers (obviously, much less so when considering political feasibility). But without governance that clarifies our values and converts them into sufficiently robust policy mechanisms to ensure compliance, confusion and distrust leave carbon management playing too small and too ambiguous a role.

The most direct way to overcome the confusion and distrust is to clearly define the values by creating statute and policy. Too often, labels such as "transparency" or "hardest to decarbonize activities" or "local community benefits" are too ambiguous to create positive change, and only serve to prevent clean energy and climate solutions of any kind.

If we convert these terms into policy design metrics that represent societal values, we can also limit acceptable outcomes to only those aligned with the stated values. These solutions may not gain consensus appeal, as society does not yield consensus values, but they will help in defining and enforcing the aforementioned limits.

In the remainder of this policy digest, we provide an update on the progress toward this articulation of values in the United States and on what remains to be done. Along the way, we attempt to correct some outdated claims about the current state of carbon management technologies and policies.

1 Moral hazard is a term that derives from economics, which arises when preventative measures are not taken, and further justified with the existence of insurance. In the context of carbon dioxide emissions, CCS, and CDR, moral hazard is most often used to describe the unwanted side effect of insulating notoriously carbon-bearing industries from the risks of their activities.

THE EMERGENCE OF "CARBON MANAGEMENT" IN U.S. POLICY

Carbon management is a "catch-all" term that covers both CCS and CDR activities, like direct air capture (DAC). Yet, we must not conflate or interchange CCS with DAC. CCS is a tool for mitigating fossil CO_2 emissions from industrial and power sources, while CDR is a climate tool for removing CO_2 from the accumulated pool in the atmosphere.

These are different tools, with different objectives, all under the umbrella of our portfolio approach to addressing climate change. The only potential for overlap between these tools is the downstream management of CO_2. Managing gigatonnes of CO_2 whether avoiding emissions from entering the atmosphere through CCS or removal from the atmosphere, through methods like DAC or biomass with carbon removal and storage (BiCRS), requires building out the capacity of geologic storage, and to return the gigatonnes of CO_2 back to the geosphere.

Globally, CCS activities in 2023 increased by 50%, which increased capture potential to 361 $MtCO_2$/yr, including 26 new operational and in-construction facilities. This brings today's total to 41 CCS projects in operation, 26 under construction, and 325 in development. Details and locations of projects are described in detail in the *2023 Status Report* from the Global CCS Institute (Global CCS Institute 2023).

The U.S. Bipartisan Infrastructure Law (BIL) through roughly $2.5 billion of funding requires the U.S. government to install six integrated CCS demonstrations, with four on power and two on industrial units over the next several years ("Carbon Capture Demonstration Projects Program," n.d.). There's an additional $1 billion focused specifically on pilots, which are required for the more nascent integrated carbon capture technologies coupled to decarbonizing industrial emissions such as cement, paper, steel, aluminum, and glass.

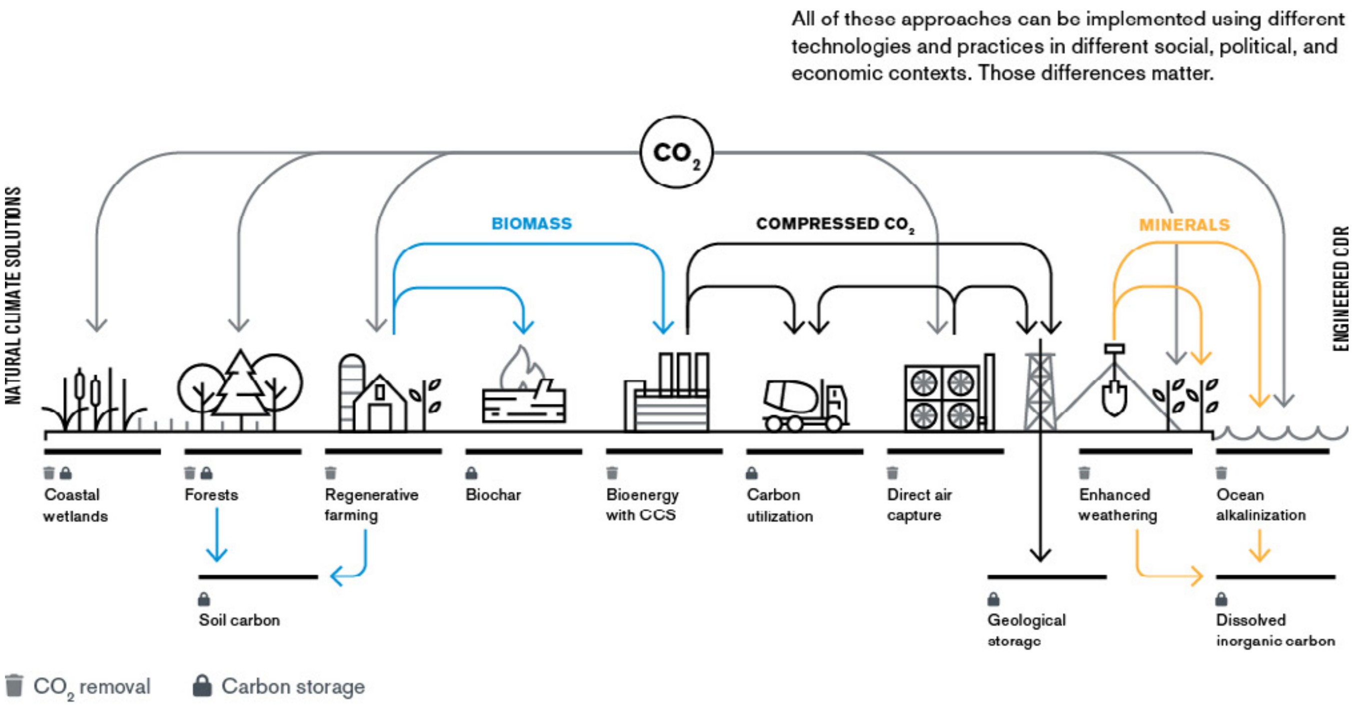
While the idea of CCS typically conjures images of large coal and natural gas fired power plants, the reality is that CCS is a critical tool for decarbonizing industrial supply chains, which contain significant *process emissions* as opposed to fuel or combustion emissions indicative of power plants. Process emissions are those that are produced through a chemical reaction, such as calcining limestone to produce lime ($CaCO_3 \rightarrow CaO + CO_2$).

BIL also contains a provision at $2.25 billion to seed the buildout of geologic storage of CO_2 in the United States over the next several years ("Funding Notice: Bipartisan Infrastructure Law: Carbon Storage Validation and Testing" 2023). The Department of Energy (DOE) has a goal of increasing CO_2 geologic storage capacity from millions of tonnes in the U.S. today to 65 $MtCO_2$ in 2030 and 100 $MtCO_2$ in 2035. Building out the geologic storage capacity is critical for advancing the scale-up of CCS in addition to DAC and BiCRS.

Roughly $700 million have been invested on expanding the geologic storage capacity over the past year through *DOE's CarbonSAFE program* ("Funding Notice: Bipartisan Infrastructure Law: Carbon Storage Validation and Testing" 2023), with roughly $1.5 billion more to invest. DOE, through its network of National Laboratories, works closely with the Environmental Protection Agency (EPA) to assist in the technical evaluation of Class VI permits for dedicated storage of CO_2. The DOE currently has applications for over 160 CO_2 injection wells in the queue. *EPA recently developed a tracker* (US EPA 2023) for transparency for applicants in terms of progress and communities where geologic storage may be sited.

CDR, compared to CCS is more complicated, with many unique approaches—each with their own risk/benefit profile. These technologies will be counted on to deliver on three points: 1) to help lower net CO_2 emissions in the near-term; 2) to counterbalance hard-to-abate residual emissions in the mid-term; and 3) to sustain net-negative CO_2 emissions when deployed at a scale higher than the residual emissions.

FIGURE 1: A PORTFOLIO WITHIN A PORTFOLIO: THE MANY APPROACHES TO CARBON DIOXIDE REMOVAL



Source: Morrow et al. 2020

Examining any one carbon removal pathway reveals even more complexity: take DAC as an example. There are multiple approaches to carrying out DAC, from solvent-based to solid sorbent, large-scale versus modular, passive versus powered intake, in addition to a number of emerging technologies.

Through the BIL, DOE has launched a *Pre-Commercial DAC Technology Prize* ("DAC Pre-Commercial Technology Prize | HeroX," n.d.). There are currently 433 innovators registered, divided into 91 teams. The *recent award announcement* for the $3.5 billion BIL provision on DAC Hubs, made awards to meet industry where the technology is at today (from concept, to front-end engineering design (FEED), to demonstration) ("Funding Notice: Bipartisan Infrastructure Law: Regional Direct Air Capture Hubs" 2023). DOE announced $1.2 billion for two DAC Hub demonstrations and $100 million across roughly 20 projects spanning concept through FEED all across the United States.

MOORING U.S. CARBON MANAGEMENT TO VALUES

Thought leaders across the CDR community and the U.S. government have been responsibly communicating that the role of CDR is not to offset emissions in areas where viable technologies and approaches already exist for decarbonization, but rather to counterbalance the truly hard to decarbonize sectors. This is emphasized in the *U.S. Fifth National Climate Assessment*; DOE's *Fossil Energy and Carbon Management's Strategic Vision*; and the *CDR Primer Chapter 1, The Case for Carbon Dioxide Removal: From Science to Justice* (Jay et al. 2023; "Strategic Vision: The Role of FECM in Achieving Net-Zero Greenhouse Gas Emissions," n.d.; Bergman and Rinberg 2021).

While there is no universally accepted optimal ratio for emission reductions to emission removals, some organizations, like the IPCC and the Science Based Target Initiatives (SBTi) suggest that CDR is likely necessary for the last 5–10% of emissions

(Intergovernmental Panel On Climate Change (Ipcc) 2023; SBTi 2023; “Net Zero Emissions by 2050 Scenario (NZE)—Global Energy and Climate Model—Analysis” 2023). Still, that relatively small amount equates to billions of tonnes by mid-century.

Today we are at the level of 1000s of tonnes of durable CDR. One does not plant pepper seeds in the ground in September in Pennsylvania: there simply won’t be enough time for those plants to fully mature before frost hits. The same math applies to CDR: if we do not plant the seeds of investment today, we won’t have enough time to scale-up to the billion tonne-scale required by mid-century (roughly 25 years from now) (Nemet et al. 2023; Smith et al. 2023).

Through DOE’s investment in the Carbon Negative Shot tens of millions of dollars annually are supporting the growth of durable carbon removals across the broader portfolio including oceans, agriculture, forests, to chemicals. For projects to be awarded they need to include robust monitoring, reporting, and verification (MRV), which will also help us to better understand the timescales that this carbon can be adequately removed. The goal of the effort is to build out durable CDR and to scale from 1000s of tonnes of durable removal today to millions of tonnes over the next decade to achieve gigatonne scale by mid-century.

This recent attention to quality in the public sector has been mirrored by an equal turning of the tide in the private sector. As an example, Microsoft has been a frontrunner among corporations in articulating with MRV framing the distinction between low, medium, and high durability CDR.

Carbon Direct and Microsoft published *Criteria for High-Quality Carbon Dioxide Removal* in 2023 (Carbon Direct and Microsoft 2023). A detailed list of *Microsoft’s 1.5M tCO_2 removal contracts* is available online (“Microsoft Power BI,” n.d.). This transparency allows for other corporations to learn from and hopefully adopt Microsoft’s principles for responsible CDR as this market is primarily voluntary today.

In addition to durability, *DOE’s investments* prioritize projects that aim to achieve maximum climate benefit (“Regional Direct Air Capture Hubs Selections for Award Negotiations,” n.d.). For instance, coupling DAC to dedicated storage of CO_2 rather than using CO_2 as a feedstock for enhanced oil production maximizes the net CO_2 returned to the geosphere.

In addition, when DAC is coupled to natural gas as an energy input with CCS, it becomes critical that when evaluating the net carbon removed one accounts for the impacts across the entire supply chain of natural gas including upstream methane emissions. Ultimately, coupling DAC to renewables achieves the greatest efficiency in terms of CO_2 management and maximizes the climate benefits of CDR, as long as the renewables are truly available and wouldn’t have otherwise displaced fossil resources that would have avoided CO_2 emissions to begin with.

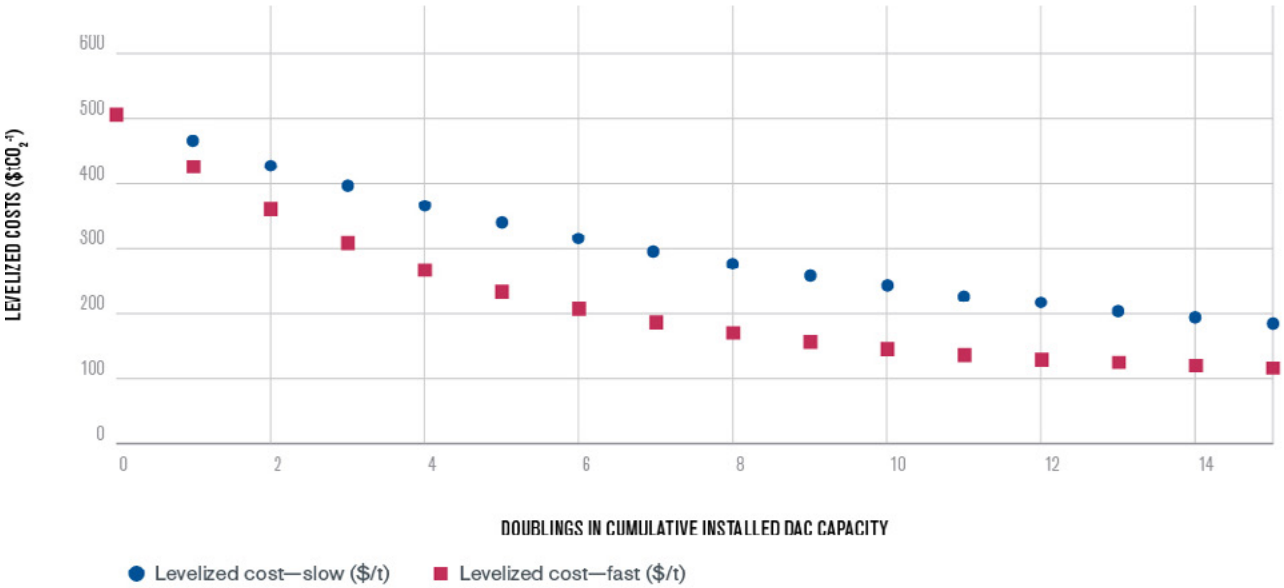
An opportunity exists when examining the basis of how renewable energy avoids emissions when it’s generated with the potential to displace fossil fuel generation. This climate benefit is legitimate and tangible, but also geographically variable. Countries and regions with strong potential for renewable energy development, like solar, wind, geothermal and hydroelectric power, often have more decarbonized grids as a result.

This means that the generation and importation of renewable energy for those grids already have marginal climate returns, and those returns will continue to diminish over time as grids decarbonize on a global scale. This is an important and notable consideration, given the potential for this to dismiss and delay the deployment of DAC, which may have higher climate returns.

Direct air capture, for instance, could be a compelling solution to this dilemma, enabling the redistribution of economic benefits to developing regions, while using an opportunity to gain access to renewable electrons that likely would not have been available to other markets.

Niche opportunities in the near-term scale could scale well with DAC growth, while longer-term trends in grid decarbonization open more opportunities as DAC scales. DAC can also catalyze the deployment of renewable energy in areas that need access by subsidizing the economic constraints associated with remote infrastructure and last-mile connectivity (e.g., by financing substation build-out).

FIGURE 2: DEPLOYMENT-ENABLED COST REDUCTIONS OF DAC UNDER SLOW AND FAST LEARNING RATES



Source: McQueen et al. 2021

The more glaring failure of the opportunity cost argument is that in looking solely at the climate benefits today, it ignores any value associated with technological learning. Part of the reason for the precipitous drop in renewable energy costs is that investment in accelerating adoption enabled these technologies to move down their learning curves, a phenomenon that proves as we invest into an activity and learn how to do it, it will invariably become cheaper over time.

Figure 2 shows how this could work for DAC using a "fast" learning rate of 20% (similar to what solar has experienced) and a "slow" learning rate of 10% (closer to what wind turbine technology has experienced). Deployment-enabled learning drives costs down—and toward—the $100/t target set by DOE.

The principal idea is that while most accept that technologies become cheaper over time, it is actually the *deployment* of technologies that yields these cost reductions, not time in and of itself. Hence, one cannot argue that we should not invest in DAC because it is too expensive when investment is *required* to make it less so. Early investments in DAC coupled with DOE's Carbon Negative Shot, DAC Hubs, enhanced incentives in 45Q, and the voluntary market are all necessary to move DAC down the cost curve.

POLICY AND PROGRAM RECOMMENDATIONS

To develop substantially effective policy surrounding the emerging field of CCS and CDR requires a holistic view of the technologies, their potential role in decarbonization, and their potential impacts on society and the environment. These facets can be further emphasized through the development of reporting structures and programs that promote the interdisciplinary work to forge interactions between technologists, social scientists, communities, and industry.

These results can be elicited through actions, which include, but are not limited to:

- Instituting academic and workforce training programs focused on working at the interface of incumbent industry and new projects, increasing human capital with relevant expertise, e.g., climate solutions focus within engineering, business, and social science curricula.
- Developing and elevating interdisciplinary programs, projects, and grants resulting in expanding the training for engineers to consider social sciences, and vice versa, to promote meaningful engagement between industry and communities.

- Crafting policy to promote the fossil fuel workforce to transition into clean energy jobs.
- Developing transparent reporting structures to ensure that demonstrations and deployment of carbon management are not simply enabling fossil fuels or overburdening communities. This reporting structure should also account for safety of downstream carbon value chain activities, like CO_2 transport and storage, and co-benefits, such as decreasing air pollution.
- Building informed, robust community benefits agreements, and further educating communities on the emerging technologies and their respective rights. These community benefit agreements need to ensure carbon management can take care of people at the end of the day.

CONCLUSION

Policy not securely moored to clearly recognizable and broadly accepted policy values generates a weak social license that is unlikely to build a durable and sufficient policy outcome. A decent regard for the legitimate concerns of many interested parties demands a shared understanding of the values driving that social license. Carbon management through advancing CCS and CDR needs a more robust social license in order to deliver its essential contribution to climate change mitigation.

This policy digest has summarized recent progress in both the technologies and the policies that are advancing a new phase of carbon management potential and action. This threshold moment makes it all the more critical that we take stock of the values we seek in carbon management and thereby clarify and amplify these values in an inclusive discussion that leads to broad commitment. Only then can a durable policy regime supporting the net-zero framework move forward with an arithmetic of emissions reductions and removals that minimizes the damage of the climate crisis.

BIBLIOGRAPHY

Bergman, Andrew, and Anatoly Rinberg. 2021. "The Case for Carbon Dioxide Removal: From Science to Justice." In *CDR Primer*, edited by Jennifer Wilcox, Benjamin Kolosz, and Jeremy Freeman.

"Carbon Capture Demonstration Projects Program." n.d. *Energy.gov*. Accessed January 20, 2024. *https://www.energy.gov/oced/CCdemos*.

Carbon Direct, and Microsoft. 2023. "Criteria for High-Quality Carbon Dioxide Removal." New York, NY: Carbon Direct.

"DAC Pre-Commercial Technology Prize | HeroX." n.d. Accessed January 20, 2024. *https://www.herox.com/DAC-pre-commercial-tech*.

"Funding Notice: Bipartisan Infrastructure Law: Carbon Storage Validation and Testing." 2023. *Energy.gov*. December 2023. *https://www.energy.gov/fecm/funding-notice-bipartisan-infrastructure-law-carbon-storage-validation-and-testing*.

"Funding Notice: Bipartisan Infrastructure Law: Regional Direct Air Capture Hubs." 2023. *Energy.gov*. August 2023. *https://www.energy.gov/fecm/funding-notice-bipartisan-infrastructure-law-regional-direct-air-capture-hubs*.

Global CCS Institute. 2023. "Global Status of CCS 2023: Scaling up through 2030." *https://res.cloudinary.com/dbtfcnfij/images/v1700717007/Global-Status-of-CCS-Report-Update-23-Nov/Global-Status-of-CCS-Report-Update-23-Nov.pdf?_i=AA*.

Intergovernmental Panel On Climate Change (Ipcc), ed. 2023. "Mitigation Pathways Compatible with Long-Term Goals." In *Climate Change 2022—Mitigation of Climate Change*, 1st ed., 295–408. Cambridge University Press. *https://doi.org/10.1017/9781009157926.005*.

Intergovernmental Panel On Climate Change (IPCC), ed. 2023. "Technical Summary." In *Climate Change 2022—Mitigation of Climate Change*, 1st ed., 51–148. Cambridge University Press. *https://doi.org/10.1017/9781009157926.002*.

IPCC. 2022a. "AR6 WGIII: CDR Factsheet." *https://www.ipcc.ch/report/ar6/wg3/downloads/outreach/IPCC_AR6_WGIII_Factsheet_CDR.pdf*.

———. 2022b. "Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change." Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. 10.1017/9781009157926. *https://www.ipcc.ch/report/ar6/wg3/*.

Jay, A.K., T.A. Dahl, R.S. Dodder, B.D. Hamlington, A. Lustig, K. Marvel, P.A. Méndez-Lazaro, et al. 2023. "Ch. 1. Overview: Understanding Risks, Impacts, and Responses." In *Fifth National Climate Assessment*. Washington, D.C.: U.S. Global Change Research Program. *https://doi.org/10.7930/NCA5.2023.CH1*.

McQueen, Noah, Katherine Vaz Gomes, Colin McCormick, Katherine Blumanthal, Maxwell Pisciotta, and Jennifer Wilcox. 2021. "A Review of Direct Air Capture (DAC): Scaling up Commercial Technologies and Innovating for the Future." *Progress in Energy* 3 (3): 032001. *https://doi.org/10.1088/2516-1083/abf1ce*.

"Microsoft Power BI." n.d. Accessed January 20, 2024. *https://app.powerbi.com view?r=eyJrIjoiZTU5OTYwN2EtOTI3Ni00NGE0LThjNWItZTUzZTFlNWIxNzFhIiwid CI6ImMxMzZlZWMwLWZlOTItNDVlMC1iZWFlLTQ2OTg0OTczZTIzMiIsImMiOjF9*.

Morrow, David R., Michael S. Thompson, Angela Anderson, Maya Batres, Holly J. Buck, Kate Dooley, Oliver Geden, et al. 2020. "Principles for Thinking about Carbon Dioxide Removal in Just Climate Policy." *One Earth* 3 (2): 150–53. *https://doi.org/10.1016/j.oneear.2020.07.015*.

Nemet, Gregory, Jenna Greene, Finn Müller-Hansen, and Jan C. Minx. 2023. "Dataset on the Adoption of Historical Technologies Informs the Scale-up of Emerging Carbon Dioxide Removal Measures." *Communications Earth & Environment* 4 (1): 397. *https://doi.org/10.1038/s43247-023-01056-1*.

"Net Zero Emissions by 2050 Scenario (NZE)—Global Energy and Climate Model—Analysis." 2023. IEA. 2023. *https://www.iea.org/reports/global-energy-and-climate-model/net-zero-emissions-by-2050-scenario-nze*.

"Regional Direct Air Capture Hubs Selections for Award Negotiations." n.d. *Energy.gov*. Accessed January 20, 2024. *https://www.energy.gov/oced/regional-direct-air-capture-hubs-selections-award-negotiations*.

SBTi. 2023. "SBTi Corporate Net-Zero Standard." Science Based Targets Initiative. *https://sciencebasedtargets.org/resources/files/Net-Zero-Standard.pdf*.

Smith, Stephen M., Oliver Geden, Jan C. Minx, Gregory F. Nemet, Matthew Gidden, William F. Lamb, and Carter Powis. 2023. "The State of Carbon Dioxide Removal Report 2023," January. *https://policycommons.net/artifacts/3444788/untitled/4244826/*.

"Strategic Vision: The Role of FECM in Achieving Net-Zero Greenhouse Gas Emissions." n.d. *Energy.gov*. Accessed January 20, 2024. *https://www.energy.gov/fecm/strategic-vision-role-fecm-achieving-net-zero-greenhouse-gas-emissions*.

US EPA, OW. 2023. "Current Class VI Projects under Review at EPA." Data and Tools. United States. April 27, 2023. *https://www.epa.gov/uic/current-class-vi-projects-under-review-epa*.

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