WORLD RESOURCES INSTITUTE

WORKING PAPER

FOUNDATIONAL QUESTIONS ON CARBON REMOVAL IN THE UNITED STATES

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EXECUTIVE SUMMARY

Highlights

- The ambitious emissions reduction measures modeled in most global emissions pathways are not enough to achieve the Paris Agreement targets for limiting temperature rise. In these pathways, it is also necessary to undertake efforts to remove carbon dioxide (CO_2) from the atmosphere at the gigaton scale—billions of metric tons per year globally.
- Several approaches and technologies are candidates for large-scale carbon removal. Many of these hold promise but also face challenges and limitations. In many cases, their full potential remains uncertain. Given this uncertainty, a portfolio-based approach to carbon removal technologies would improve prospects for achieving CO_2 removal on a large scale.
- Carbon removal approaches would require effective governance, accounting procedures, and policy safeguards to ensure productive deployment and prevent counterproductive or harmful deployment.
- Although carbon removal has raised some concerns about the degree to which it might detract from ongoing efforts to reduce emissions, it has the potential to broaden the public policy agenda on climate change in ways that bring additional stakeholders and resources to the table.

CONTENTS

Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues. Working papers may eventually be published in another form and their content may be revised.

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Carbon removal is the process of removing CO_2 from the atmosphere and storing it. Carbon removal is intended to help address global temperature rise by reducing atmospheric concentrations of CO_2, a major greenhouse gas.

If deployed successfully at a large scale, carbon removal could substantially contribute to limiting global temperature rise. Global scenario analysis indicates that the prospects of achieving the temperature targets established in the Paris Agreement are greatly improved if CO_2 can be removed on a large scale. The need for carbon removal intensifies if the world is unable to make deep reductions in global emissions by 2030. Other measures that are currently excluded from global models because they are viewed as too costly, or because adoption is driven by factors other than cost, could also help to achieve temperature targets. Such measures include noncoercive population growth reduction and widespread lifestyle changes such as shifting diets to less greenhouse-gas-intensive foods. However, even then, global scenario analysis suggests the global economy will need to reach carbon neutrality in the second half of the century to maintain a likely chance of achieving the Paris Agreement targets. Achieving carbon neutrality without carbon removal would require eliminating all emissions, including from sectors like aviation that are difficult to fully decarbonize.

Advancing carbon removal is an exercise in creating options through research, development, early-stage deployment, and other efforts to address major challenges. Each of the candidate approaches faces its own set of challenges, potential pitfalls, and limitations. Given the uncertainty, a portfolio of approaches and technologies could yield greater chances for achieving large-scale benchmarks for carbon removal.

Competing arguments have surfaced about the potential benefits and risks of introducing carbon removal to global climate action efforts. Some argue that carbon removal could introduce new demands for scarce mitigation resources or be used by policymakers to justify delays in emissions reduction efforts. Others argue that carbon removal could broaden the public policy agenda on climate change in ways that bring additional interests and resources to the table and yield new coalitions for making progress.

Carbon removal may yield benefits as well as pose risks for people and ecosystems. Potential benefits relate to improved soil health, agricultural productivity, and a range of ecosystem services, as well as prospects to create new markets and industries. If deployed without proper safeguards, however, some approaches could result in the displacement of food production or the loss of natural ecosystems, or fail to deliver expected climate benefits. Managing these risks will require effective policy safeguards and the ability to measure and monitor deployment to ensure safeguards work as intended.

ABBREVIATIONS

BECCS	bio-energy with carbon capture and storage
CO_2	carbon dioxide
DACS	direct air capture and storage
DOD	Department of Defense
DOE	Department of Energy
GHG	greenhouse gas
R&D	research and development
SRM	solar radiation management

INTRODUCTION

The Paris Agreement established a goal of limiting global temperature rise to well below 2˚C above pre-industrial levels, and to pursue efforts that limit the increase even further, to 1.5˚C. These targets are intended to avoid the worst impacts of climate change. Global scenario planning models are used to identify the pace and scale of mitigation efforts that will be required to meet a target for temperature rise. The large majority of modeled scenarios indicate that ambitious greenhouse gas (GHG) emissions reductions alone will not be enough to have a likely chance of achieving the Paris Agreement targets (Nemet et al. 2018; IPCC 2015). These models therefore combine ambitious emissions reductions with the removal of carbon dioxide (CO_2) from the atmosphere (Minx et al. 2018). However, the approaches and technologies for what is often called "carbon removal" are largely unproven at the scale that appears in these models (Fuss et al. 2018)—more than 1 gigaton of CO_2 ($GtCO_2$) annually by as soon as 2050 (Nemet et al. 2018).

This working paper serves as a primer for U.S. policymakers and the climate community on several foundational questions associated with carbon removal, including the following:

- What is carbon removal?
- What is the role of carbon removal in global climate change mitigation?
- Is large-scale carbon removal possible today?
- Is carbon removal safe and prudent?
- Does carbon removal pose conflicts or present opportunities for emissions reduction efforts?

WHAT IS CARBON REMOVAL?

Carbon removal is the process of removing CO_2 from the atmosphere and storing it.[1] Carbon removal is intended to help address climate change by reducing atmospheric concentrations of the primary greenhouse gas, CO_2. Carbon has naturally circulated from the atmosphere to forests, soils, and oceans for millennia as part of the carbon cycle. Carbon removal seeks to accelerate and augment these processes.

Carbon removal can take a variety of forms (NRC 2015). The top panel of Figure 1 illustrates the natural carbon cycle and major sources of anthropogenic emissions. The bottom panel illustrates a range of carbon removal approaches. These approaches were selected because they are most commonly referenced in the literature (see Box 1, Mulligan et al. 2018a, 2018b). These include the following:

Box 1 | **CarbonShot: Creating Options for Carbon Removal at Scale in the United States**

In its series CarbonShot: Creating Options for Carbon Removal at Scale in the United States [wri.org/carbonremoval], WRI presents three thematic working papers that assess prospects for carbon removal in the United States:

- Foundational Questions on Carbon Removal in the United States
- Carbon Removal in Forests and Farms in the United States
- Technological Carbon Removal in the United States

The second and third papers in this series cover the challenges and limitations facing major carbon removal approaches and technologies, and the policies that could begin to address those challenges. In the course of this assessment, the team gleaned several insights related to key foundational questions on carbon removal. This paper is informed by several cross-cutting assessments of carbon removal approaches and syntheses of the literature (e.g., NRC 2015; Smith et al. 2015; Minx et al. 2018; Fuss et al. 2018; Nemet et al. 2018); consultations with 34 subject matter experts from academia, government, and civil society; and two roundtable events—one in San Francisco, California, and one in Washington, DC. Participants included a subset of the experts that were consulted previously, as well as a number of practitioners from the broader climate change mitigation community of practice. These practitioners included analysts and decision-makers in the nonprofit and philanthropic sectors.

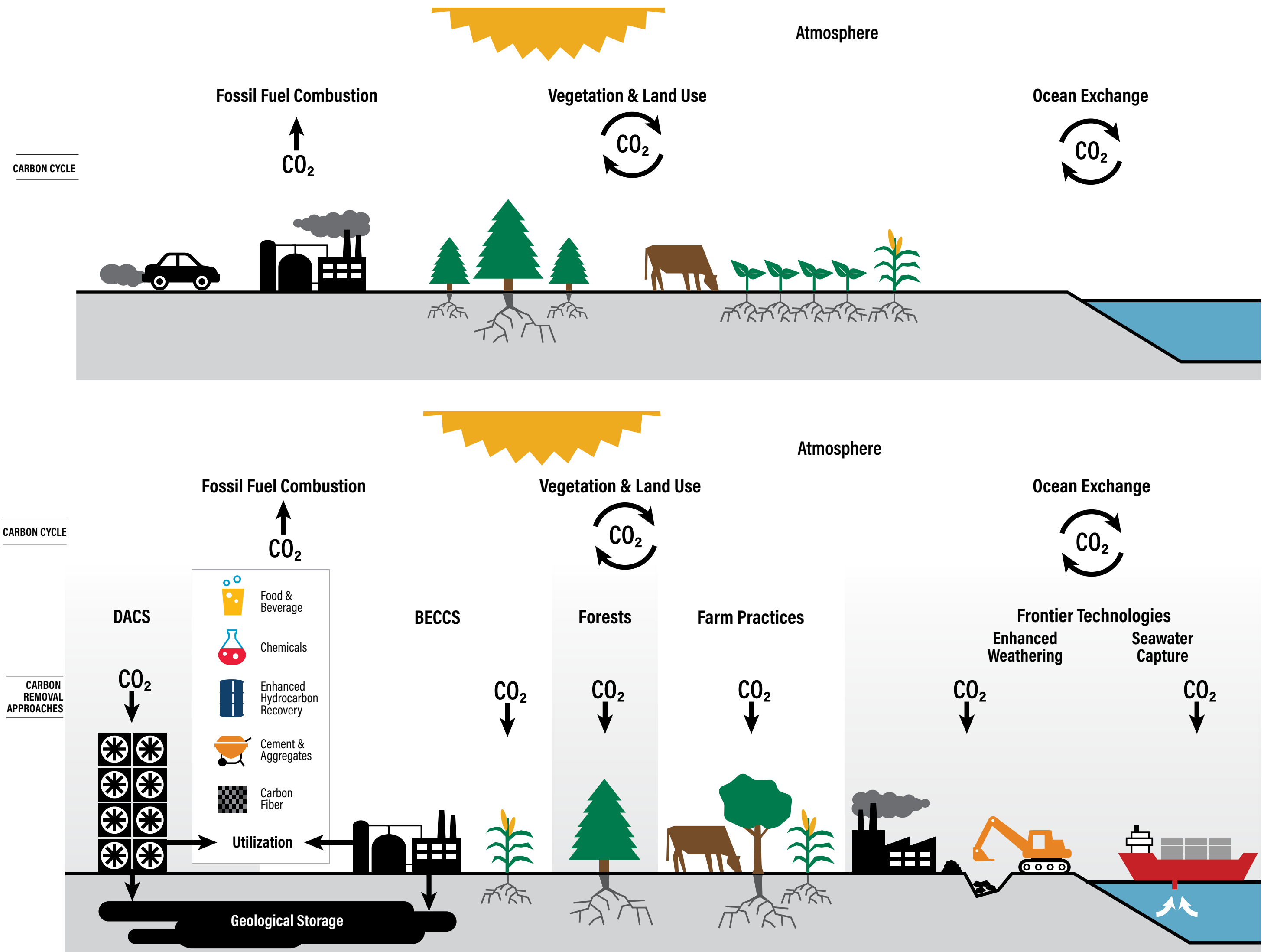
- Forest and soil carbon. Several approaches seek to increase carbon removal and storage in forests and farms. These include increasing tree cover, changing forest management practices, integrating trees into agricultural systems (i.e., agroforestry), or applying a variety of soil management practices to build carbon in cropland and rangeland soils.
- Bio-energy with carbon capture and storage (BECCS). BECCS involves converting biomass to heat, electricity, or liquid fuel while capturing and storing the CO_2 emitted in the process. BECCS can reduce emissions by displacing more GHG-intensive sources of energy, and can result in the net removal of CO_2 from the atmosphere under certain circumstances.
- Direct air capture and storage (DACS). DACS captures CO_2 directly from the ambient air through chemical scrubbing processes and stores it underground or in products.
- Frontier technologies. Several technologies are in the very early stages of development and/or their utility and efficacy for carbon removal is nascent, including biochar, plant breeding and engineering, enhanced weathering, and seawater capture. These technologies remove CO2 directly from the atmosphere, accelerate natural carbon removal processes, or facilitate the permanent storage of carbon removed by natural means.

Other approaches to carbon removal include those that rely on alterations to ocean ecosystems. For example, one approach in the literature involves adding nutrients like iron to upper ocean waters to trigger algal blooms that fix and then store carbon for some period of time in sediments (Fuss et al. 2018). This approach is excluded from this assessment due to the international legal ramifications of the United States unilaterally pursuing such an option (see Fuss et al. 2018) and the high risks of disrupting a functioning ecosystem (Hale and Dilling 2011).

Carbon removal is distinct from emissions reduction in that it removes CO_2 that is already in the atmosphere, rather than preventing CO_2 and other GHGs from being released into the atmosphere in the first place. For example, capturing CO_2 in the flue gas of natural gas–fired power plants is a form of emissions reduction because it reduces CO_2 emissions but not a form of carbon removal because it does not remove CO_2 that is already in the atmosphere.

Carbon removal is also distinct from solar radiation management (SRM) approaches. Examples of SRM include spraying aerosols into the stratosphere to deflect incoming solar radiation, installing mirrors in space to deflect solar radiation, and altering how much sunlight is reflected by the Earth's surface. By definition, SRM does not remove CO_2 from the atmosphere but rather seeks to reduce global warming by reflecting solar radiation back out into space (NRC 2015). SRM is not considered in this assessment.

Figure 1 | **The Carbon Cycle and Carbon Removal Approaches for Augmenting the Net Transfer of Carbon from the Atmosphere**



Source: Adapted from U.S. DOE NETL 2018; Minx et al. 2018.

WHAT IS THE ROLE OF CARBON REMOVAL IN GLOBAL CLIMATE CHANGE MITIGATION?

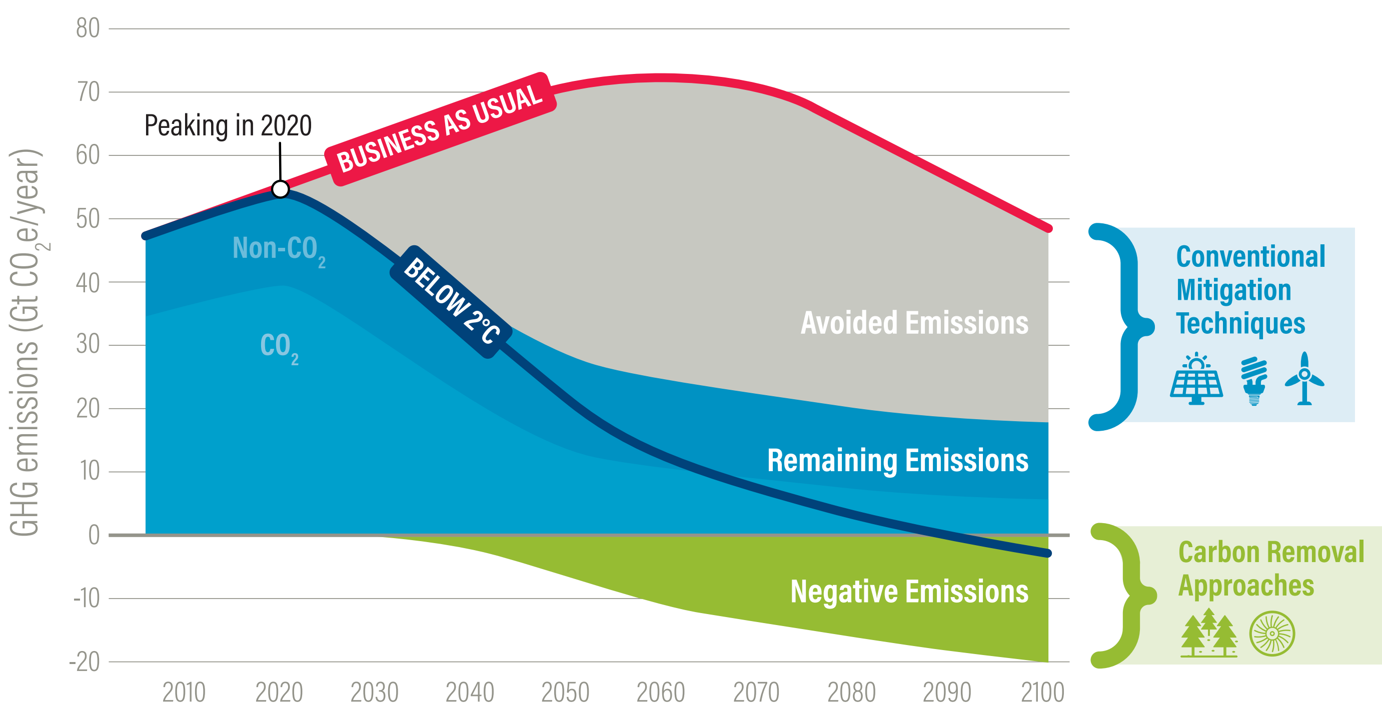
The world faces a dwindling "carbon budget," which is the amount of CO_2 emissions that humanity can emit in the future while still having a likely chance of limiting global temperature rise to a given target. Current estimates of the carbon budget are about 1,000 $GtCO_2$ (billion metric tons of CO_2) for the 2°C target and 0–200 $GtCO_2$ for the 1.5°C target (Minx et al. 2018).[2]

Current mitigation efforts are insufficient. The latest Emissions Gap Report published by the United Nations highlights a large disparity between the emissions reductions needed to achieve the Paris Agreement temperature targets and national pledges currently on the books. If that gap is not closed by 2030, it is "extremely unlikely" that the 2°C goal could still be reached (UNEP 2017). In Figure 2, the top line (in red) illustrates a 2012 policy baseline that incorporates national commitments made at the 2009 United Nations Climate Change Conference in Copenhagen.

Ambitious emissions reductions are critical. In least-cost pathways for achieving the Paris Agreement temperature targets, emissions peak no later than 2020 and deep emissions reductions are required across all sectors soon thereafter. The Emissions Gap Report considers a wide range of emissions reduction measures with estimated costs up to US$100/$tCO_2$ to bring the global economy in line with pathways to the Paris Agreement targets by 2030. Among others, these measures include the following:

- Increasing wind power installed capacity four- to fivefold and solar capacity twelvefold by 2030, relative to 2016
- Achieving 2 $GtCO_2$/year of carbon capture and storage in 2030
- Applying best management practices across one-third of global croplands
- Achieving near-zero energy use for all new buildings globally starting in the 2020–25 period
- Halting deforestation, reducing meat and dairy consumption, and reducing food waste (UNEP 2017)

Figure 2 | **Complementary Role of Carbon Removal to Emissions Reductions**



Note: This is a notional scenario consistent with an at least 66 percent chance of limiting global warming to below 2°C. Some residual gross greenhouse gas emissions (both CO_2 and non-CO_2) will remain at the end of the century even with ambitious climate action because they are too difficult or costly to remove entirely. Once negative emissions exceed those that remain, net zero emissions is reached. Faster and/or deeper emissions reductions could reduce the role for carbon removal; slower and/or weaker emissions reductions would increase the need for carbon removal.

Source: Adapted from UNEP 2016.

The emissions reductions of these types of measures are reflected in the gray area through 2030 in Figure 2. The pace of change continues and additional measures are also needed post-2030 to remain on the pathway to the Paris Agreement targets.

However, emissions reduction measures modeled in most global emissions pathways are not enough to have a likely chance of achieving the Paris Agreement targets. Models studied in the UNEP Emissions Gap Report are unable to achieve the 1.5˚C target with emissions reductions alone. Some of the same models are able to achieve the 2˚C target in some scenarios with just emissions reductions, but the majority are not (Nemet et al. 2018). Further delay in ambitious global climate action quickly puts the 2˚C target out of reach with emissions reductions alone (Fuss et al. 2018).

If the modeled emissions reduction measures are insufficient, then options will be needed for faster and deeper emissions reductions, or for removing CO_2 from the atmosphere—or both. Some emissions reduction measures are currently excluded from global models because they are considered too costly or because adopting the measure is not driven by cost (e.g., some lifestyle changes), making them difficult to include in cost-minimization models (vanVuuren et al. 2018). While potentially challenging, some of these measures could be adopted in the medium to long term. Examples include reducing population growth through better education and access to health services; adopting cultured meat; intensifying agricultural production; and making lifestyle changes related to diet, transportation, heating, cooling, and domestic appliance use. A recent study found that these measures, if successful, could substantially contribute to temperature stabilization. However, even when combined with optimistic assumptions related to energy efficiency, electrification, and the integration of renewable energy, these measures appear to be insufficient to meet the 1.5˚C goal (vanVuuren et al. 2018).

How then does carbon removal factor in? Figure 2 provides an illustrative example of carbon removal (green area) working in tandem with deep reductions in combined CO_2 and non-CO_2 emissions (gray area) to keep pace with a pathway consistent with the 2˚C target (dark blue line). In this illustrative example, carbon removal is also used in the second half of the century (and beyond) to offset residual emissions from sectors that are difficult to mitigate entirely, so that the global economy reaches carbon neutrality. Critically, carbon removal could also be used to reduce atmospheric concentrations of CO_2 over time if the world overshoots the carbon budget associated with temperature targets—although the scale of that function is limited by the potential scale of deployment, and thus remains uncertain.

Today's models estimate a wide range of cumulative carbon removal between 2011 and 2100: 400–1,000 $GtCO_2$ to meet the 1.5˚C target and 0–800 $GtCO_2$ to meet the 2˚C target (Minx et al. 2018). These ranges reflect differences in assumptions and approaches across models. The precise scale of carbon removal that will be needed over the remainder of this century to achieve the Paris Agreement targets is uncertain given inherent challenges in modeling the pace and nature of policy shifts, economic development, technology shifts (e.g., fossil fuels to renewables), population growth, and other factors. The primary takeaway from available models is that, in most scenarios, carbon removal is needed at a large scale.

IS LARGE-SCALE CARBON REMOVAL POSSIBLE TODAY?

Advancing carbon removal is an exercise in creating options. Although several carbon removal approaches and technologies can be deployed today (see Figure 1, bottom panel), each faces its own set of challenges and limitations on the way to deployment at a large scale. In many cases the full technical and economic potential of available carbon removal technologies remains uncertain. Some approaches may be further limited by policy safeguards such as those installed to protect food production and natural ecosystems (Smith et al. 2015).

Given the uncertainty each faces, a broad portfolio of approaches and technologies could yield greater opportunities for achieving large-scale benchmarks for carbon removal than betting on just one or two. The approaches and technologies evaluated could together deliver carbon removal on the gigaton scale (more than 1 $GtCO_2$ per year) within the United States, but significant efforts would be needed over the coming decades to reach that scale (Mulligan et al. 2018a; Mulligan et al. 2018b). Several approaches, including BECCS, DACS, and the frontier technologies would need further development and cost reduction before large-scale deployment could be achieved. Other approaches would rely on changes in land management across millions of landowners. Some in the land sector risk displacing food production and natural ecosystem conservation, and so would depend on successes in parallel food security efforts like shifting diets and increasing agricultural productivity on existing agricultural lands in order to manage these risks.[3]

Through innovation and sustained efforts to address the challenges facing each of the candidate approaches and technologies, carbon removal has the potential to become viable at a large scale in the coming years and decades. The undertaking may appear to some (if not many) to be staggering, yet there are examples of similar feats in U.S. history. For example, in 1934, the U.S. Forest Service set out to plant shelterbelts to battle the Dust Bowl. By 1940 it had planted 200 million trees from Texas to North Dakota. Similarly, between 1941 and 1945, the U.S. government, along with collaborators in academia and industry, developed a substitute for natural rubber (which was scarce during World War II) and catalyzed large-scale production. In 1961, a manned lunar mission seemed out of reach, yet less than a decade of concerted effort made it happen. In 2011, the Department of Energy (DOE) launched a SunShot Initiative to reduce the cost of solar power by 75 percent by 2020. Through aggressive research and development (R&D) and cross-industry collaboration, the DOE hit the target for utility-scale solar three years early.

IS CARBON REMOVAL SAFE AND PRUDENT?

Carbon removal may have the potential to provide benefits for people and ecosystems, beyond reducing atmospheric concentrations of CO_2. Some land sector approaches are associated with improved soil health and agricultural productivity, water resources protection, improved air quality, and other benefits to ecosystem services (Smith et al. 2013; Molnar and Kubiszewski 2012; Kroeger et al. 2014; Nowak et al. 2014; Derpsch et al. 2010). Public policies and R&D spending to advance technological carbon removal might spark new markets and industries, such as the utilization of captured CO_2.

However, several of the available technologies and land management approaches will also require good governance and policy safeguards to ensure safe and prudent deployment of carbon removal approaches and to prevent counterproductive or harmful deployment. Some of the risks include misallocating resources, displacing food production, and disrupting natural ecosystems.

Misallocation of resources

The difficulty of accounting for the actual net impact of some carbon removal approaches could result in the misallocation of scarce resources—or even counterproductive investments (i.e., increases in atmospheric GHG concentrations). These accounting challenges relate to additionality and indirect land use change effects, scientific uncertainty, and high transaction costs for measurement and monitoring.

For example, extending forest rotation length in one area to sequester more carbon could result in deforestation in another area to satiate global timber or fiber markets. The net effect for carbon flows might be zero or worse. Similarly, crediting BECCS for carbon removed from the atmosphere by energy crops may fail to account for the carbon lost or forgone if those energy crops directly or indirectly displaced or precluded forested land uses (Searchinger and Heimlich 2015). On agricultural lands, investing in policy incentives for soil management practices may not provide the intended climate benefits if soil carbon, which is difficult to measure and monitor at a large scale, does not accumulate as expected.

Displacement of food production

Afforestation and reforestation are inherently land intensive. Bioenergy is also land intensive, especially if dedicated energy crops are used as feedstock. As a result, large-scale afforestation and dedicated energy crops could result in displacing food crops and livestock, unless crop and livestock yields on existing agricultural lands are sufficiently intensified. As the supply of food or fiber is reduced, all else equal, the prices of those commodities will increase and some portion of the lost supply will be replaced from elsewhere. In the case of fiber, that may involve forest harvest in other areas that could reverse carbon gains. In the case of food, that may involve clearing forest or tilling grasslands that could have a similar offsetting effect. In addition, the resulting increases in food prices could negatively affect food security for the world's most vulnerable, against the backdrop of growing global demand for food (Searchinger and Heimlich 2015).

Disruption of natural ecosystems

Without proper safeguards, large-scale incentives for bioenergy or afforestation could result in the conversion of natural ecosystems to commercial energy or monoculture tree plantations for carbon in ways that do not provide for the broader set of services provided by natural ecosystems (Robledo-Abad et al. 2017; Creutzig et al. 2015; Hall et al. 2012).

These risks pose real challenges for policymakers. Effective policy safeguards will rely on measuring and monitoring deployment to ensure such safeguards work as intended. For example, minimizing the risk that bioenergy will displace natural ecosystems or food production at a large scale might require that policies only incentivize the

use of “sustainably harvested” forest and crop residues and waste biomass as feedstocks. This raises challenging questions around defining “sustainably harvested” and monitoring compliance. Similarly, policies aimed at increasing forest carbon could prioritize changes in the management of existing forests—like actively replanting following harvest—and reforestation on nonagricultural lands. This may be difficult for carbon removal approaches that affect the land sector, especially given challenges in monitoring and attributing land use change.

DOES CARBON REMOVAL POSE CONFLICTS OR PRESENT OPPORTUNITIES FOR EMISSIONS REDUCTION EFFORTS?

The prospect of carbon removal has raised questions in public discourse and in the literature about the degree to which carbon removal would support or undermine global efforts to reduce emissions. On the one hand, some concerns relate to the possibility that carbon removal might weaken incentives to pursue ambitious emissions reductions, or introduce competition for resources. On the other hand, the choice between reducing emissions and removing carbon may be false. Global scenario analysis indicates both are needed, pursuing emissions reductions and carbon removal in some instances can be complementary, and carbon removal may broaden the public policy agenda on climate change in ways that bring additional interests and resources to the table—allowing for progress on both fronts at the same time.

Weakened incentive for reducing emissions?

One concern is that an expectation of large-scale carbon removal could weaken the incentive of decision-makers and their constituents to aggressively pursue actions that would prevent emissions in the first place, especially if carbon removal approaches are misperceived as “silver bullets.” If carbon removal then fails to be deployed at the scale envisioned, atmospheric concentrations of greenhouse gases will be higher than they would have otherwise been (Anderson and Peters 2016; EASAC 2018). This concern is sometimes referred to as the “moral hazard” argument against carbon removal approaches.

However, although large-scale carbon removal changes the cost and technology profiles of modeled scenarios over the course of the century, there are no scenarios in which emissions reductions are not needed at a level of ambition that far exceeds current efforts (UNEP 2016; Minx et al. 2018). This is due to the limitations and relatively high costs of carbon removal. Rather than softening decision-makers’ commitment to emissions reductions, this key finding in the literature should instead serve as a call to action for enhancing ambition for both emissions reduction and carbon removal.

Competition for resources?

A second cited concern is that scarce government, corporate, and/or philanthropic resources that may otherwise be invested in emissions reduction measures could be diverted to carbon removal—even if decision-makers view carbon removal as a supplement and not a substitute for emissions reductions (Gardiner et al. 2010).

In practice, these tradeoffs may or may not occur. Policy mechanisms like procurement standards and regulatory requirements that do not rely on new appropriations are unlikely to come at the expense of other policy investments. For example, whether the Department of Defense (DOD) increases procurement of cross-laminated timber should not affect research funding in the DOE, or even the DOD’s procurement of renewable energy. Other important investments in mitigation—such as U.S. contributions to the Green Climate Fund, which finances low-emission and climate-resilient development in developing countries—draw on appropriations from different corners of the federal budget that are controlled by different sets of appropriators than the federal science, technology, natural resources, and agriculture spending that would support carbon removal.

Perhaps the most salient risk of resource competition presents itself within government agencies like the DOE that are critical for advancing both carbon removal and emissions reduction technologies, and are subject to a single set of appropriators. For example, DOE appropriators could conceivably provide funding for carbon removal research in the DOE’s Office of Science at the expense of appropriations to the DOE’s Office of Nuclear Energy. Or, agency officials could program funds within flexible spending authorizations toward carbon removal technologies at the expense of emissions reduction technologies.

However, investments and divestments within government budgets are balanced across a much broader set of needs and appropriator interests. When federal policymakers seek to increase funding for a government program, they typically look for other areas where spending can be reduced to “offset” the increase. These offsets tend to be in areas where existing spending is no longer needed, not being used efficiently, or unpopular with constituents. For example, the federal budget for fiscal year 2016 proposed a funding increase to the Environmental Protection Agency to implement the Clean Power Plan. That increase

was largely offset by savings derived from consolidating facilities and a shrinking workforce.

Climate change–related spending is also a small portion of overall federal spending, regardless of administration—i.e., approximately $20 billion out of nearly $4 trillion, or about 0.5 percent (OMB 2013). It is not necessarily the case that new funding for carbon removal would be appropriated at the expense of other climate-related funding. Furthermore, the current emissions trajectory—given current resource allocation to mitigation efforts—is well short of what is needed to achieve the Paris Agreement targets. In other words, success will require "growing the pie."

False choices in public discourse?

A third cited concern is that misperceptions may fuel false choices between ambitious emissions reduction and carbon removal in public discourse, even though the global models illustrate that both are needed. Misperceptions of the promise of carbon removal could be leveraged by interests vested in the status quo to justify delays in emissions reductions, or by policymakers as a convenient excuse for delayed action (Shue 2017). A similar dynamic may also occur in reverse, where interests vested in current emissions reduction measures use the "moral hazard" argument or concerns about resource tradeoffs to justify inaction on carbon removal (Minx et al. 2018).

Complementary investments?

There may be areas where efforts to advance carbon removal can complement efforts to reduce emissions. For example:

DACS systems require a significant amount of low-carbon energy (NRC 2015). Thus, deploying low-carbon energy technology, which is critical for reducing emissions, is also an important measure for carbon removal. In theory, DACS could also supplement demand for renewable electricity, enabling and supporting the "overbuild" necessary to reach deeper levels of grid integration. However, this potential has not yet been robustly evaluated in the literature.

Policies to advance land sector carbon removal could line up well with efforts to reduce emissions from the land sector. For example, government incentives and support to landowners for improved forest management practices and reforestation could improve the profitability of holding and stewarding forestland, which could offset pressures to convert that land to other uses—a source of emissions. Urban forestry has been shown to reduce energy usage. Several agricultural practices can reduce emissions as well. For example, conservation tillage can reduce fuel consumption on the farm, and compost can reduce the need for nitrogen-based fertilizers.

Advancements in carbon capture and storage technology—an important emissions reduction measure—can help to advance carbon removal technologies by establishing CO_2 pipeline infrastructure, validating geological storage sites, and mobilizing markets for CO_2 utilization. Each of these developments could facilitate the deployment of BECCS and DACS.

A bigger tent?

Carbon removal can appeal to different sets of political interests. Carbon removal could broaden the public policy agenda on climate change at the state and federal levels to include economic opportunities for rural communities, communities currently dependent on emissions-intensive industries, and emerging industries. These opportunities could include government incentives for land stewardship, policy changes that boost farm and forest profitability while sequestering more carbon, and government R&D spending and policy incentives for CO_2 capture, storage, and utilization technologies and markets. Broadening the agenda has the potential to bring additional interests and resources to the table, yield new coalitions for state and federal climate policy, and open windows for constructive policy changes even in political climates typically unfavorable to mitigation policy. This could benefit both emissions reduction and carbon removal.

CONCLUSION

If the large majority of global models are right, achieving the Paris Agreement targets will require removing CO_2 from the atmosphere in addition to ambitious GHG emission reductions. Nonetheless, the approaches and technologies for doing so face challenges, potential pitfalls, and limitations. Some pose risks to people and the planet if deployed without proper safeguards. Also, for carbon removal to play a meaningful role in stabilizing the climate, it must supplement, not become a substitute for, deep decarbonization of the economy. There is no evidence that carbon removal could serve as a viable alternative to emissions reduction.

Creating viable options for safe and prudent carbon removal at a large scale in the United States will require a concerted effort—likely sustained action over several decades. It will be important to advance this effort in ways that are complementary to mitigation efforts, and to avoid false choices between the two.

ENDNOTES

1. For a deeper discussion of definitional issues affecting carbon removal, see Minx et al. 2018.

2. It should be noted that a recent study (Millar et al. 2017) has suggested that the carbon budgets may be larger than initially thought due in part to estimates of warming realized to date, but this discussion is still unresolved in the literature (Fuss et al. 2018).

3. These challenges are further explored in the companion papers in this series—"Carbon Removal in Forests and Farms in the United States" (Mulligan et al. 2018a) and "Technological Carbon Removal in the United States" (Mulligan et al. 2018b).

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity and human well-being.

Our Challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision
We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.