STATE OF THE SCIENCE

CARBON DIOXIDE REMOVAL'S ROLE
IN ACHIEVING PARIS AGREEMENT'S GOALS

INSTITUTE *for* CARBON REMOVAL
LAW AND POLICY

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More than a decade's worth of research finds that carbon dioxide removal (CDR), which consists of nature-based and technological efforts to remove carbon pollution from the atmosphere and safely store it, will be necessary to achieve the goals of the Paris Agreement. Meeting the goals of the Paris Agreement and stopping the worst impacts of climate change raises important questions about the role of CDR, how much of it is required and when, and how it can be deployed responsibly. This resource helps answer these questions on CDR, which is also known as Negative Emissions Technologies (NETs), by drawing on IPCC reports, a CDR Primer, and a report from the Institute for Carbon Removal Law and Policy.

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WHY MEETING THE PARIS AGREEMENT MATTERS

The U.S. and countries across the world are suffering from the impacts of climate change today. Extreme weather events, including unprecedented wildfires in the West Coast and flooding in the Gulf Coast, are threats to public safety and the economy. Vulnerable communities are at particular risk, and often include low-income communities and communities of color that are the most exposed to climate impacts. In order to avert the worst impacts of climate change and protect humanity, every country in the world has signed on to the Paris Agreement.[1]

The Paris Agreement has a goal of limiting climate change to well below 2°C , preferably 1.5°C, compared to pre-industrial levels (which is 3.6°F and 2.7°F, respectively). The Intergovernmental Panel on Climate Change (IPCC), a UN scientific agency that aggregates and endorses existing peer-reviewed science from around the world, warns about the significant impact that every small degree means for the world. Hans-Otto Pörtner, Co-Chair of IPCC Working Group II, has stated: "Every extra bit of warming matters, especially since warming of 1.5°C or higher increases the risk associated with long-lasting or irreversible changes, such as the loss of some ecosystems."

A landmark IPCC report published in 2018, "Special Report on Global Warming of 1.5°C," finds that impacts at 2°C will be much worse than previously projected, meaning 2°C is no longer a safe goal to avoid the worst impacts of climate change. The IPCC's latest report published in 2021 underscores this finding. The world is already experiencing the impacts of climate change and extreme weather is projected to worsen as the climate warms. The impacts of a 1.5°C versus 2°C world are stark:

- Limiting global warming to 1.5°C could reduce the number of people exposed to climate-related risks and susceptible to poverty by up to several hundred million by 2050 compared with 2°C.
- A 1.5°C world could reduce the proportion of the world population exposed to a climate-change induced increase in water stress by up to 50% compared to 2°C.
- Limiting global warming to 1.5°C rather than 2°C is projected to prevent the thawing of an area of permafrost the size of Mexico.
- Coral reefs are projected to decline by more than 99% at 2°C but up to 30% can still be saved in a 1.5°C world.
- Impacts associated with forest fires are lower at 1.5°C compared to 2°C of global warming.

THE WORLD'S SHRINKING CARBON BUDGET

There is no time left to waste in meeting the goals of the Paris Agreement. Climate pollution, or greenhouse gases[2] that the world emits, especially carbon dioxide (CO_2), will remain in the atmosphere even if the world stopped adding additional pollution today. CO_2 emitted by human activity is already fueling the increase of extreme weather events and climate impacts around the world.

The amount of future warming will depend largely on the world's cumulative CO_2 emissions. This includes both the CO_2 that's still in the atmosphere from past emissions and the amount of CO_2 the world emits today and in the future from the

1 The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 parties at COP21 in Paris, on December 12, 2015 and entered into force on November 4, 2016. Its goal is to limit global warming to well below 2˚C, preferably to 1.5˚C, compared to pre-industrial levels.

2 Greenhouse gases trap heat in the atmosphere. These gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. By increasing the concentration of greenhouse gases in the atmosphere, the world is amplifying the planet's natural greenhouse effect and turning up the dial on global warming.

burning of fossil fuels and other sources of emissions. Scientists are able to estimate the total amount of CO_2 humanity can still emit without exceeding any particular temperature target. That amount of CO_2 is called a carbon budget.[3]

The IPCC's most recent Sixth Assessment report, Working Group I, underscores that climate impacts are here and now and that the world's carbon budget is shrinking. The report estimates that the world has a remaining budget of approximately 400 gigatons[4] of CO_2 for a two-thirds chance of limiting warming to 1.5°C, and 500 gigatons of CO_2 for a fifty percent chance. As a point of reference, one gigaton is one billion metric tons, which is the equivalent mass of approximately 10,000 fully loaded U.S. aircraft carriers. The U.S. emitted an estimated 5.1 billion metric tons of energy-related CO_2 in 2019 and has continued to shrink the world's carbon budget since the IPCC report was released, highlighting the challenge of keeping the carbon budget in check.

Even though models suggest slightly different amounts for the remaining carbon budget, there is overwhelming consensus that the world needs to reduce emissions as quickly as possible, underscored by the most recent IPCC report. According to the IPCC report, the world is currently on a pathway to overshoot the 1.5°C Paris Agreement target and even the 2°C target. Exceeding 2°C of warming puts the world at even greater risk of reaching irreversible climate impacts and passing a series of tipping points that will further exacerbate the impacts of climate change.

3 Modelling a carbon budget also includes assumptions about the trajectory of non-CO_2 emissions. Cutting non-CO_2 emissions substantially, such as methane, increases a carbon budget and vice versa.

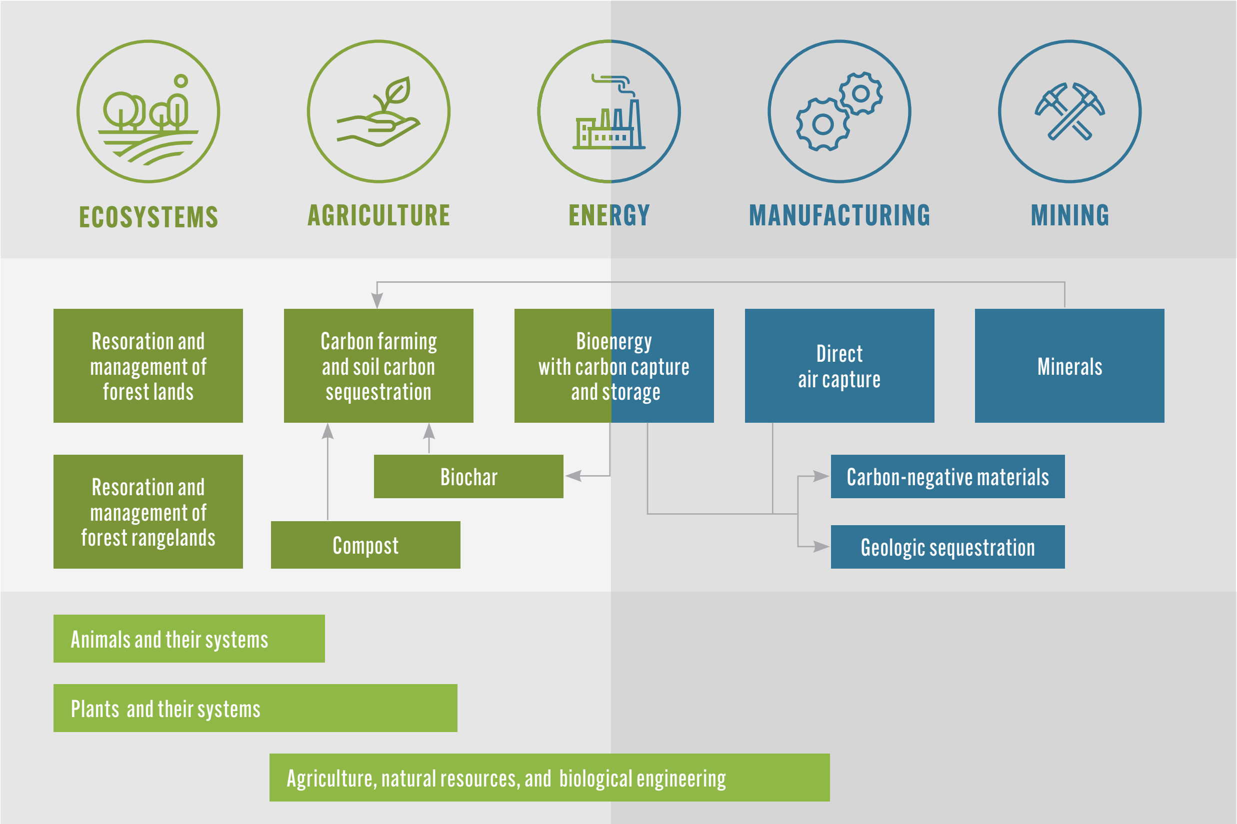
4 A gigaton is a unit of mass equivalent to one billion metric tons (2.2 trillion pounds), and is often used when discussing human carbon dioxide emissions. All of humanity's carbon dioxide emissions currently equal around 40 gigatons per year, climbing to 50 gigatons of carbon dioxide equivalent when other gases that contribute to global warming are factored in. Keeping this figure of 40–50 gigatons of current emissions in mind can be helpful when trying to understand the magnitude of carbon removal called for by scientific assessments.

THE ROLE OF CARBON DIOXIDE REMOVAL IN MEETING THE PARIS AGREEMENT

CDR is the process of removing existing carbon dioxide pollution from the atmosphere and locking it away for decades, centuries, or longer. The IPCC 2018 report (Global Warming of 1.5°C) and 2021 report (Sixth Assessment Report, Working Group I) both identify CDR as crucial to limiting warming to 1.5°C. The total amount of CDR required to meet the 1.5 degree goal will depend upon the speed and scale of stopping climate pollution.[5]

One comparison of CDR to the carbon budget is to consider the carbon pollution that the world is emitting now as garbage being added to a landfill. The world needs to stop adding more garbage, or carbon pollution, to the landfill by rapidly deploying climate solutions like energy efficiency, solar panels and wind turbines. But even after no more garbage is added, there are still existing emissions (or garbage) that need to be addressed if the landfill is overflowing. CDR is a way of addressing all of the garbage in the landfill, including the legacy emissions that will continue to exist in the atmosphere and cause dangerous climate impacts even after the world stops adding new climate pollution.

5 Multiple reports have reached similar conclusions about the need for carbon removal to limit warming to 1.5°C, including "Pathways limiting warming to 1.5°C: a tale of turning around in no time."



Terrestrial Carbon Dioxide Removal Has Many Approaches. *Source: EPSDM, UC Berkeley.*

CARBON DIOXIDE REMOVAL APPROACHES

CDR methods can be grouped into two main buckets:

- **Nature-based solutions**, which use forests, agricultural systems, existing natural sinks and marine environments to capture and store carbon.
- **Technology-based solutions**, including technologies that mimic natural processes. An example is Direct Air Capture, which uses large industrial vacuums to remove carbon from the atmosphere and store it underground. Nature cannot sustainably do all the work because the land area needed is too great and there is already competition for what land can be used for. The world needs additional approaches to avoid displacing farmers and encroaching on Indigenous lands.

Just as the world needs to mobilize all sectors and actors to pursue a multi-faceted approach to reduce carbon emissions, it also needs a diverse portfolio of carbon removal approaches. Nature-based and technology solutions can, and should, work in tandem with one another. Some carbon removal methods are already in use — China has planted vast new and expanded forests. Other forms of CDR, like Direct Air Capture, build on technologies that have been filtering to remove CO_2 for decades (including scuba diving, submarines, and the Apollo space mission).

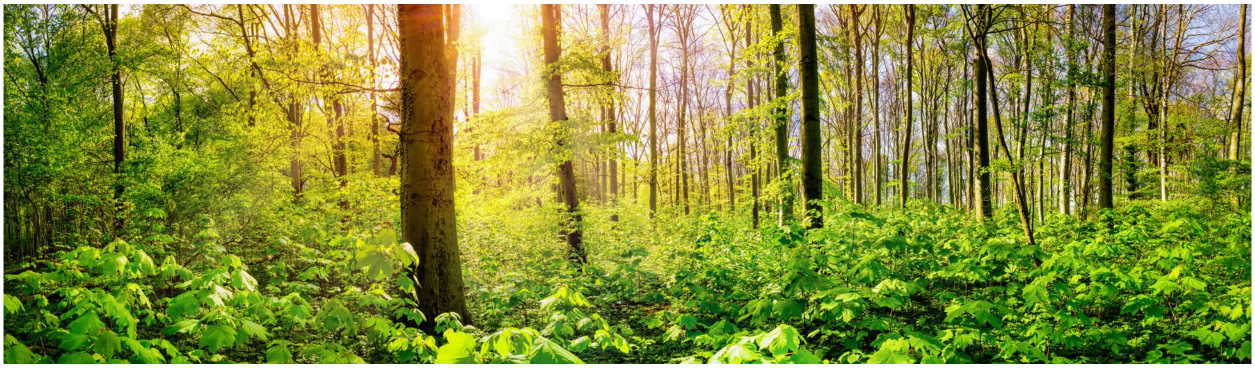
All CDR approaches, from tree planting to mineralizing CO_2 with basalt, have co-benefits and drawbacks. For this reason, deploying a complementary set of CDR solutions suited to unique local socioeconomic and biogeophysical conditions can help ensure that CDR benefits communities. Reducing atmospheric concentrations of CO_2 — currently over 400 parts per million, up roughly 25% since the Industrial Revolution — would require scaling multiple CDR efforts enormously (while continuing to reduce emissions).

At the present, carbon removal deployment is constrained by cost and other considerations, such as required land area for nature-based solutions and the high cost of technological solutions (which are projected to decrease over time). The same scientific studies that emphasize the need for carbon removal also underscore that it only makes sense to look at CDR options alongside mitigation options, including renewables and electric vehicles that prevent future emissions. CDR cannot be a replacement for the important work of reducing emissions, but both efforts must work in tandem.

CALCULATING PATHWAYS TO MEET THE GOALS OF THE PARIS AGREEMENT

There is scientific consensus that the world needs some level of CDR to meet the goals of the Paris Agreement, but a crucial question remains: how much carbon removal is required to meet this goal? To answer this, scientists use Integrated Assessment Models (IAMs), a suite of tools that map pathways that keep the world on track to meet the goals of the Paris Agreement. IAMs use economic, ecological, and technological assumptions to model global emissions mitigation trajectories. Inside the model, mitigation measures typically compete on the basis of cost, so that the model will select more carbon removal when it provides a more cost-effective way to reduce net emissions.

Direct Air Capture fans at a Climeworks facility in Switzerland.



Nearly all IAMs suggest that multiple gigatons of carbon removal will need to be removed annually to meet the goals of the Paris Agreement. Despite the relatively high cost of CDR today, models deploy it at scale because the world's remaining carbon budget is small and mitigation efforts will now be insufficient to hold warming below 1.5°C on their own or to eliminate emissions-intensive efforts like long haul aviation. Some IAM models overshoot their concentration or temperature targets early on — sometimes by a substantial margin — and then use carbon removal later to still achieve their original target. These so-called "overshoot" scenarios may see temperatures go above 1.5°C to then be brought back down via removal. In these scenarios, CDR matters even more as a crucial way to remove excess carbon pollution.

In an extensive analysis of the results of different published IAM studies, Fuss *et al.* (2018) found that scenarios achieving 1.5°C included carbon removal deployment by 2050 ranging from 1.3 to 29 gigatons of CO_2 removal per year, with most falling between 5 and 15 gigatons of carbon removal. Multiple reports from other scientific experts reach similar conclusions. A 2017 report from the United Nations Environmental Program finds that meeting the Paris Agreement goals will require annual carbon removal of 10 gigatons a year by 2050 and 20 gigatons a year by 2100. A report on carbon removal from the National Academy of Sciences mirrors the same numbers of the United Nations Environment Program report.

Scientists have identified some scenarios in which the world holds warming below 1.5°C without large-scale carbon removal, although this becomes all but impossible if current emissions trajectories continue through 2030. Scientists have modelled a few scenarios that meet the 1.5°C target with limited use of technological carbon removal, but these require dramatic progress in other kinds of ambitious mitigation efforts such as battery storage and expansion of forest land. These may incur other types of co-benefits or drawbacks, especially for countries in the Global South who have to balance how to best utilize farmland and forests. These scenarios require reducing global emissions by 80% over the next 10 years, which would require a mobilization scale greater than World War II and impose significant challenges for developing countries.

Because IAM models prioritize cost savings, social justice modelling is also an important determinant for the types of carbon removal that are most equitable. The least expensive option (expressed in terms of cost per ton of CO_2 removed or avoided) is not necessarily the best one from a broader perspective that considers environmental impacts and social justice. Social justice considerations include instances, for example, where reducing emissions would be associated with depriving people of the means to satisfy their basic needs, such as food security.

INTEGRATING SOCIAL JUSTICE AND GOVERNANCE CONSIDERATIONS IN CARBON REMOVAL DEPLOYMENT

Carbon removal impacts need to be fully assessed to realize all benefits and to identify any potential risks. Conversations about carbon removal will benefit from the evaluation of which forms of carbon removal to use; where, when, and how much; and the policies and institutions needed to foster responsible carbon removal. Investing in CDR now aligns with scientific consensus that the world needs some level of it to prevent the worst impacts of climate change, which can work to protect the people who are and most at risk of suffering from climate impacts.

While science has advanced significantly in this topic in the last decade, various CDR approaches have unique co-benefits and drawbacks. Some are known to scientists, while others require further research and demonstration. Externalities of CDR may not be apparent until deployment has reached a certain scale. Therefore, a participatory approach involving a broad set of stakeholders can help to minimize the potential risks now and as CDR matures.

The ways in which society interacts with CDR and its by-products needs consensus building and further investigation. In short, right-sizing CDR to not just the biophysical needs — the amount of CO_2 removal needed to reverse climate impacts — but also the socioeconomic circumstances, such as its impacts on frontline communities — is a crucial part of responsible deployment.

There are two primary reasons to open up a more expansive conversation about carbon removal: (1) the weight of scientific analysis suggests that carbon removal at large scales will likely be necessary to combat climate change; and (2) there is the potential for the development of CDR to be done poorly or result in negative side-effects. Such effects include relying too much on natural solutions such as forests at the expense of growing food, or not fully consulting with communities on the deployment of technology solutions. An ongoing conversation about the responsible deployment of CDR is urgently needed.

SOURCES

This primer is a summary of information contained in IPCC reports, a larger CDR Primer Textbook, a report from the Institute for Carbon Removal Law and Policy, and sources linked to throughout this document.