CENTER FOR CLIMATE AND ENERGY SOLUTIONS

TECHNOLOGY WORKING GROUPS

More Than Carbon

The Co-benefits and Value Proposition of Engineered Carbon Removal

October 2025

Engineered carbon removal (ECR) is a form of carbon dioxide removal (CDR) that uses human-made technologies to capture carbon dioxide from ambient air or oceans. In some cases, ECR accelerates the speed of natural carbon dioxide uptake and/or transfers the captured carbon dioxide to more permanent storage through technological means.[1]

While ECR is essential for mitigating the impacts of climate change, it also provides a range of economic and broader environmental co-benefits.

Author:

Diandra Angiello

HIGHLIGHTS

Beyond Carbon Cuts: Engineered carbon removal (ECR) technologies like DAC, BiCRS, ERW, and mCDR not only mitigate climate change but also deliver co-benefits including job creation, wildfire risk reduction, soil health improvements, and ocean ecosystem resilience.

Jobs and Stability: By the time the highly durable CDR sector (including ECR) scales to storing 100 million metric tons of carbon dioxide annually, it could create 95,000-130,000 US jobs. These jobs provide stable operations and maintenance roles that deliver significant benefits to legacy energy communities and industrial workforces nationwide.

Global Edge: ECR enhances U.S. competitiveness by producing lower-emission products, like sustainable aviation fuels, to meet international standards. This strengthens energy-intensive, trade-exposed industries and positions the U.S. to capitalize on the rapidly expanding global carbon removal credit market.

Innovation Unlocks Value: Continued federal investment in innovation is essential to unlocking the full potential of ECR and other emerging technologies. Sustained funding for research, development, and demonstration not only accelerates the creation of new ECR approaches with added value but also enhances existing approaches by making them more cost-effective, energy-efficient, and scalable.

Key ECR Approaches and Their Associated Co-Benefits

Direct air capture (DAC)

Low concentrations of carbon dioxide can be directly extracted from ambient air. Using fans or passive exposure, air is passed over a solid or liquid material that chemically attracts carbon dioxide. Carbon dioxide is then released from the capture material using heat, resulting in a high-purity carbon dioxide stream that can be geologically sequestered or used to create carbon-based products, such as long-lasting materials (e.g., concrete) and low-carbon fuels (e.g., synthetic sustainable aviation fuel or "e-fuels").[2]

Oil and gas workers across the United States stand to benefit from DAC, which relies on their existing expertise in carbon dioxide injection and geological storage. Beyond the oil and gas industry, DAC also shares significant skill overlap with other trades and industrial operations, including construction, metalworking and assembly, and engineering.[3] In addition, DAC systems can utilize industrial waste heat. Refineries and petrochemical complexes, for example, generate large volumes of low-grade heat that can be repurposed to power DAC operations.[4] This co-location with existing industry not only improves the techno-economics of DAC projects, but also provides an additional revenue stream for host facilities through the generation of CDR credits.

Biomass with carbon removal and storage (BiCRS)

The natural process of photosynthesis can be leveraged by planting vegetation as a low-cost method to capture carbon dioxide from the atmosphere. The resulting biomass can then be converted or stored in ways that prevent the captured carbon dioxide from being released back into the atmosphere due to wildfires or natural decomposition. One option is to bury the biomass directly underground. Alternatively, it can be processed at high temperatures in a low-oxygen environment to produce carbon dioxide and/or useful byproducts like biochar or bio-oils. These outputs can be geologically sequestered or used to create carbon-based products.[5]

Like DAC, BiCRS approaches that involve geological storage can leverage the technical proficiencies of legacy energy communities. BiCRS also draws on existing skills found within broader industry, such as transportation and metalworking and assembly.[6] When implemented sustainably, BiCRS can help reduce underbrush and forest waste in fire-prone areas—lowering wildfire risk and improving forest health.[7] Additionally, BiCRS can provide a path for the responsible removal of agricultural waste, reducing the harmful air quality impacts of clearing fields through burning.[8]

Bioenergy with carbon capture and storage (BECCS) is a form of BiCRS that generates energy from the conversion of biomass into heat, electricity, or liquid or gas fuels. The carbon emissions produced from the bioenergy conversion are then captured and geologically stored or used to create carbon-based products.[9] BECCS has the potential to generate carbon-free, dispatchable power that can run 24/7, supporting grid stability, especially in rural areas and/or ones with emerging data centers. This not only contributes to greater energy abundance at a time of growing electricity demand, but also provides a secondary revenue stream to help offset the cost of carbon removal.

TABLE 1: ENGINEERED CARBON REMOVAL CO-BENEFITS

Co-benefits	DAC	BiCRS	ERW	mCDR
Creates carbon-based products	✓	✓		✓
Leverages skills present in legacy energy communities	✓	✓		✓
Leverages skill overlap with existing trades and industrial operations	✓	✓	✓	✓
Provides an additional revenue stream for industries that generate waste heat	✓			
Generates CDR credits	✓	✓	✓	✓
Reduces wildfire risk		✓		
Improves forest health		✓		
Supports better air quality		✓		
Generates clean electricity		✓ (BECCS)		
Increases crop productivity			✓	
Enhances crop resilience to heat and pests			✓	
Improves soil health			✓	
Mitigates ocean acidification				✓

Note: This is a simplified representation of co-benefits across ECR approaches. It does not fully capture key nuances—for example, some co-benefits may carry different weight or levels of impact depending on context and deployment. A portfolio approach—using multiple ECR approaches in combination rather than relying on a single solution—is essential to maximize overall benefits.

Enhanced rock weathering (ERW)

The natural weathering of carbonate or silicate rocks can be accelerated by grinding them into fine particles and then distributing them across land, most commonly on agricultural fields. There, the particles react with rain and atmospheric carbon dioxide to form bicarbonate, a dissolved form of carbon dioxide that is transported through runoff into streams and rivers, eventually reaching the ocean.[10] The bicarbonate can remain dissolved in the ocean for hundreds of thousands of years, or it can react with other dissolved ions to form carbonate sediments, which store the carbon dioxide for millions of years.[11]

There are many domestic employment opportunities associated with ERW, including skilled trades and industrial occupations within transportation, mining, and construction. ERW can also improve soil health, increase crop productivity, and enhance crop resilience to heat and pests.[12]

Marine CDR (mCDR)

There are a variety of approaches that can boost the ocean's natural uptake of atmospheric carbon dioxide. One approach is called ocean alkalinity enhancement (OAE), which involves adding alkaline substances to seawater. This locally raises the water's pH level, promoting a natural influx of atmospheric carbon dioxide into the water to rebalance itself. OAE offers the potential to mitigate ocean acidification by raising ocean pH levels, which could support the resilience of marine ecosystems and benefit coastal communities that rely on fisheries and ecotourism.[13] OAE can also leverage talent from existing sectors, including transportation.[14]

Another approach, known as direct ocean capture (DOC), draws seawater into a plant where electrochemical processes convert the dissolved inorganic carbon it contains into carbon dioxide. The carbon dioxide is then separated—much like in DAC—to be geologically sequestered or used to create carbon-based products. The treated seawater is then returned to the ocean to absorb more carbon dioxide from the atmosphere.[15] Like DAC, DOC involves geological storage that can utilize the established knowledge of the oil and gas industry. DOC can also make use of capabilities long established across sectors such as construction, metalworking and assembly, and engineering.[16]

>95K

jobs per year

When the CDR sector is storing 100 million metric tons of carbon dioxide annually, it is can create 95–130 thousand jobs per year.

The Value of ECR

Domestic Manufacturing and Jobs

The emerging ECR industry presents a meaningful opportunity to benefit U.S. manufacturing and industrial employment, especially within legacy energy communities. By the time the highly durable CDR sector scales to storing 100 million metric tons of carbon dioxide annually, it is projected to create between 95,000 and 130,000 jobs per year in the United States. Of these, just over one-third are estimated to result from project investment—encompassing construction, engineering, materials, equipment manufacturing, and the supply chain services needed to build and deploy projects. The remaining two-thirds are estimated to be tied to the long-term operation and maintenance of these facilities, offering stable employment across a range of technical and operational roles.[17]

Capturing Growth in the Global SAF Market

SAF demand is set to to reach a critical inflection point in 2025, driven by the implementation of blending mandates under the EU's ReFuelEU Aviation regulation and the UK's SAF mandate—policies expected to generate over 1 million metric tons of SAF demand in the EU and UK alone. While 1 million metric tons of SAF demand remains modest compared to the region's conventional jet fuel demand, it is projected to quadruple to 4 million metric tons by 2030 and continue growing as blending requirements increase. The surge in SAF demand presents the United States with a strategic opportunity to become a key exporter of SAF, but only if its fuel meets rigorous sustainability criteria embedded in these international mandates.

Source: SkyNRG and ICF, *SAF Market Outlook*, June 5, 2025, https://skynrg.com/wp-content/uploads/2025/06/SAF-Market-.Outlook-2025.pdf.

U.S. Competitiveness

With the development of policies in other countries, like the ReFuelEU Aviation regulation and the United Kingdom's sustainable aviation fuel (SAF) mandate, the United States has a growing incentive to reduce the carbon intensity of certain energy-intensive trade-exposed (EITE) industries to meet foreign country standards, particularly European ones. ECR technologies can help meet these standards by capturing carbon dioxide and converting it into lower-emission products—such as a class of SAF known as e-fuels—which are produced using clean hydrogen and captured carbon dioxide.

Export & Market Potential

Thanks to nearly a century of sustained public and private investment, the United States has developed a world-leading innovation ecosystem that stands to reap substantial economic benefits by leveraging its capacity to quickly scale and export homegrown ECR technologies worldwide. Countries such as Denmark, Switzerland, and the United Kingdom have already set explicit targets for CDR as part of their national climate strategies, and many others are moving in the same direction, with the global CDR market projected to reach $25 billion by 2029.[18]

Continued U.S. investment in ECR makes strategic economic sense given the growing global demand for high-quality carbon credits. As carbon markets expand—driven by both compliance and voluntary commitments—countries and companies alike are seeking credible, measurable carbon removal solutions. In fact, durable CDR credit demand could reach 100 million metric tons of carbon dioxide by 2030, which is double the 50 million metric tons in announced supply.[19] By leading in the development and deployment of ECR technologies, the United States can tap into a multi-billion-dollar market opportunity and generate new revenue streams through the sale of verified carbon credits internationally.

Unlocking Added Value with Innovation

The United States has long stood at the forefront of innovation by pairing public investment in new technologies with the ingenuity and scale of the private sector. These partnerships position the country to lead in the development and deployment of emerging technologies—including ECR. However, to fully realize the benefits of ECR and other emerging technologies, continued federal investment in innovation is essential. Many ECR approaches, for example, do not fit neatly into the DAC, BiCRS, ERW, or mCDR categories. Some approaches are hybrids, and many more remain undiscovered—each with the potential to deliver additional value. Unlocking these opportunities requires sustained funding for scientific research and demonstration, which can advance new pathways and improve existing ones by making them more cost-effective, energy-efficient, and scalable.

To fully realize the benefits of ECR and other emerging technologies, continued federal investment in innovation is essential

Endnotes

1 Whitney Jones, et al., The Landscape of Carbon Dioxide Removal and US Policies to Scale Solutions, (New York, NY: Rhodium Group, 2024), https://rhg.com/research/carbon-dioxide-removal-us-policy.

2 Mahmoud Abouelnaga, Engineered Carbon Dioxide Removal: Scalability and Durability, (Arlington, VA: Center for Climate and Energy Solutions, 2022), https://www.c2es.org/document/engineered-carbon-dioxide-removal-scalability-and-durability.

3 Galen Bower, Nathan Pastorek and John Larsen, The Benefits of Innovation: An Assessment of the Economic Opportunities of Highly Durable Carbon Dioxide Removal, (New York, NY: Rhodium Group, 2025), https://rhg.com/research/the-benefits-of-innovation-an-assessment-of-the-economic-opportunities-of-highly-durable-carbon-dioxide-removal/.

4 Naser Odeh, Raphael W. Apeaning, and Feras Rowaihy, "Techno-economic assessment of waste heat-powered direct air capture in the refinery and petrochemical sectors in Saudi Arabia," Carbon Capture Science & Technology, 16 (September 2025), https://www.sciencedirect.com/science/article/pii/S2772656825000909.

5 "Biomass Carbon Removal and Storage," Carbon180, updated March 2024, https://carbon180.org/pathway/biomass-carbon-removal-and-storage/.

6 Galen Bower, Nathan Pastorek and John Larsen, The Benefits of Innovation: An Assessment of the Economic Opportunities of Highly Durable Carbon Dioxide Removal.

7 Galen Bower, Nathan Pastorek and John Larsen, The Benefits of Innovation: An Assessment of the Economic Opportunities of Highly Durable Carbon Dioxide Removal; see also Audrey Denvir and Haley Leslie-Boe, Biomass Can Fight Climate Change, but Only if You Do it Right (Washington, DC: World Resources Institute, 2024), https://carbon180.org/wp-content/uploads/2024/02/Biomass-for-Carbon-Removal-Explained-_-World-Resources-Institute.pdf.

8 Monica Vaughan and Kerry Klein, "Smoke from ag burning contributes to long-term health effects for Valley Latino residents," KVPR, September 6, 2022, https://www.kvpr.org/environment/2022-09-06/smoke-from-ag-burning-contributes-to-long-term-health-effects-for-valley-latino-residents.

9 "What is BECCS?," Institute for Responsible Carbon Removal, updated June 2020, https://www.american.edu/sis/centers/carbon-removal/fact-sheet-bioenergy-with-carbon-capture-and-storage-beccs.cfm.

10 "Enhanced Rock Weathering," Carbon180, updated March 2024, https://carbon180.org/pathway/enhanced-rock-weathering/.

11 Phil Renforth and Gideon Henderson, "Assessing ocean alkalinity for carbon sequestration," Reviews of Geophysics 55, no. 3 (2017): 636-674, https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2016RG000533.

12 Galen Bower, Nathan Pastorek and John Larsen, The Benefits of Innovation: An Assessment of the Economic Opportunities of Highly Durable Carbon Dioxide Removal.

13 "Marine Carbon Dioxide Removal (mCDR)," Ocean Visions, accessed August 4, 2025, https://oceanvisions.org/ocean-alkalinity-enhancement.

14 Galen Bower, Nathan Pastorek and John Larsen, The Benefits of Innovation: An Assessment of the Economic Opportunities of Highly Durable Carbon Dioxide Removal.

15 Andrea Willigie, "These 4 companies are removing carbon dioxide from the ocean. Here's how," World Economic Forum, October 25, 2024, https://www.weforum.org/stories/2024/10/direct-ocean-capture-carbon-removal-technology.

16 Galen Bower, Nathan Pastorek and John Larsen, The Benefits of Innovation: An Assessment of the Economic Opportunities of Highly Durable Carbon Dioxide Removal.

17 Ibid.

18 "Carbon Dioxide Removals (CDR) Market Research 2025: Increasing Demand for CCUS and Growing Government Funding for Carbon Removal Projects Fueling Developments – Global Market Forecast to 2029," Businesswire, January 31, 2025, https://www.businesswire.com/news/home/20250131837425/en/Carbon-Dioxide-Removals-CDR-Market-Research-2025-Increasing-Demand-for-CCUS-and-Growing-Government-Funding-for-Carbon-Removal-Projects-Fueling-Developments---Global-Market-Forecast-to-2029---ResearchAndMarkets.com.

19 Emmy Perry et al., "Matching durable carbon removals supply and demand by 2030," McKinsey & Company, July 11, 2024, https://www.mckinsey.com/capabilities/sustainability/our-insights/sustainability-blog/matching-durable-carbon-removals-supply-and-demand-by-2030.