Strengthening Biomass Carbon Removal and Storage (BiCRS) Protocols

CLEAN AIR TASK FORCE

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About Clean Air Task Force

CATF is a nonprofit organization dedicated to advancing the policy and technology changes necessary to achieve a zero-emissions high-energy planet at an affordable cost. With more than 30 years of internationally recognized expertise on environmental policy and law, and a commitment to exploring all potential solutions, CATF is a pragmatic, non-ideological advocacy group with the bold ideas needed to address climate change and air pollution. CATF has offices in Boston, Washington, D.C., Brussels, and The Netherlands with staff working remotely around the world.

CATF's Land Systems Program advances policies and practices that best mitigate climate change while supporting livelihoods worldwide by combining analysis, policy advocacy, and communication on tradeoffs and synergies among competing uses of land and bioresources.

This report is based on a detailed technical assessment of biomass carbon removal and storage (BiCRS) protocols by a team of leading experts convened by CATF in 2025.

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Executive Summary

Biomass carbon removal and storage (BiCRS) systems combine the power of photosynthesis with engineered bioconversion technologies to remove carbon dioxide from the atmosphere and store it durably for centuries to millennia. Each year plants capture ten times more carbon dioxide than all fossil fuel emissions globally,[1] creating the opportunity for BiCRS systems to mitigate climate change at a multi-gigaton scale.[2] Many BiCRS systems deliver additional benefits by avoiding greenhouse gas emissions from biomass decay, producing valuable coproducts, and incentivizing practices and cropping systems that improve soil health and water quality.[3]

Durable carbon dioxide removal (CDR), such as BiCRS, is valuable for counterbalancing ongoing emissions in hard-to-abate sectors and ultimately for drawing down atmospheric carbon dioxide. The carbon removal potential of BiCRS remains largely untapped today. To date, only a few million tonnes (Mt) of BiCRS projects have been commercially deployed, mostly as pyrolysis facilities that produce biochar for soil applications.[4]

Financing and funding are essential to expanding the number, size, and diversity of BiCRS projects, and carbon markets are a major mechanism to channel funds. Compliance and voluntary markets issue carbon removal credits, which are bought and sold by private actors to offset anthropogenic greenhouse gas emissions (carbon dioxide, methane, and nitrous oxide).

BiCRS protocols prescribe how projects should quantify the amount of carbon removed and document that the intended removal actually occurs. Dozens of BiCRS

1 Figure 5.12 in IPCC, 2021: Chapter 5. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 673–816, doi: 10.1017/9781009157896.007.

2 Estimates range from 2 to 20 Gt CO2per year; Sandalow et al. (2020) Biomass Carbon Removal and Storage (BiCRS) Roadmap https://www.osti.gov/servlets/purl/1763937; Roads to Removal: Options for Carbon Dioxide Removal in the United States, December 2023, Lawrence Livermore National Laboratory, LLNL-TR-852901. https://roads2removal.org/

3 Roads to Removal: Options for Carbon Dioxide Removal in the United States, December 2023, Lawrence Livermore National Laboratory, LLNL-TR-852901. https://roads2removal.org/; Malone et al. (2023) Harvested winter rye energy cover crop: multiple benefits for North Central US. Environmental Research Letters. DOI:10.1088/1748-9326/acd708; Exploring Biomass Carbon Removal and Storage Scenarios for California. https://www.catf.us/resource/exploring-biomass-carbon-removal-and-storage-scenarios-for-california/

4 https://www.cdr.fyi/leaderboards

protocols have emerged over the past five years to certify carbon removals. The rapid evolution of protocols during this expansion phase can support learning and innovation in the early stages of new technology and market development. However, the proliferation of protocols without quality control can result in divergent standards that may jeopardize climate integrity. The proliferation of weak protocols for forest carbon credits[5] resulted in low-quality credits, a loss of public trust, and a weakened market.[6]

The opportunity exists to ensure the climate and market integrity of BiCRS by defining clear, rigorous protocol standards at this early stage of deployment. Durable removals are expected to become increasingly valuable both to counterbalance ongoing hard-to-abate emissions and ultimately to draw down atmospheric carbon dioxide. Strong BiCRS protocols will support industry growth and help meet this anticipated rising demand for durable CDR.

We convened a panel of experts (see Appendix A for selection details) and assessed 25 BiCRS protocols that were in use as of May 1, 2025. The assessment represents a snapshot, and several protocols have been updated since that time. Importantly, carbon credits issued under earlier versions are still circulating in the market. Therefore, prior versions remain relevant to the market. We scored approaches in protocols across four key components of the BiCRS system: (1) biomass production, (2) bioconversion, (3) long-term carbon storage, and (4) overall system design. Our goal was to determine whether these existing protocols are robust enough to ensure that certified credits represent real, verifiable, net carbon dioxide removal, and to identify where improvements are needed. This report presents our assessment results and recommendations for improving BiCRS protocols to promote market and climate integrity.

Key Findings:

- **BiCRS presents a significant opportunity for mitigating climate change** and robust, consistent protocols are needed to ensure high-quality credits and protect market and climate integrity.
- **Of the 25 protocols we assessed, 28% scored satisfactory**, providing a strong foundation for developing robust BiCRS protocols.
- **All protocols have room for improvement.** 72% of the protocols scored less than satisfactory, and all protocols include at least one fundamentally flawed approach to crucial protocol features.
- **By addressing three cross-cutting issues, protocols can further support credit integrity along with CDR scaling.** Specifically, protocols should establish appropriate system boundaries, balance rigor and flexibility, and provide consistency in greenhouse gas accounting methods.

5 Ground Truth: Can Forest Carbon Protocols Ensure High-Quality Credits? https://www.forestcarbonprotocols.org/

6 The Guardian, 2024: Market value of carbon offsets drops 61%, report finds https://www.theguardian.com/environment/article/2024/may/31/market-value-of-carbon-offsets-drops-61-aoe

Photo courtesy of Vaulted Deep.

SECTION 1

What is Biomass Carbon Removal and Storage (BiCRS)?

BiCRS represents a suite of systems that use biomass resources and bioconversion technologies paired with durable[7] storage to achieve net carbon dioxide removal (CDR) from the atmosphere (Box 1). Some BiCRS systems also produce coproducts such as bioenergy, steel,[8] and nitrogen fertilizers for crops (Figure 1).[9] To be considered BiCRS, the entire system must store more carbon in durable reservoirs than greenhouse gases it emits on a lifecycle basis.

Numerous studies have identified BiCRS as essential for climate mitigation because it is cost-effective, has high technological readiness, and is rapidly scalable.[10]

7 Durable storage is used here to describe storage in engineered reservoirs that can reasonably be expected to last for at least 100 years. Some BiCRS systems achieve permanent storage, which we consider a subset of durable storage. We consider permanent to mean BiCRS techniques with a demonstrated low risk of physical reversal for at least 1,000 years in their storage reservoir. *A Policy Framework for Scaling Up Permanent Carbon Dioxide Removal in the United States*. https://www.catf.us/resource/policy-framework-scaling-permanent-carbon-dioxide-removal-united-states/

8 Biocarbon produced via BiCRS can be used in steel production as a reductant to bind with and release oxygen molecules from the iron oxide ores. This produces carbon dioxide, which is normally released to the atmosphere. Using biocarbon in steel production is an emissions-reduction strategy; without permanent carbon capture and storage at the facility, it is not a carbon-removal strategy. The steel is a coproduct of sequestered carbon dioxide.

9 Products produced alongside CDR in BiCRS systems do not represent carbon removal products in and of themselves; some may (such as biological carbon dioxide being injected into cement or concrete), but most do not. For example, if a BiCRS system produces aviation fuel, the product (aviation fuel) may emit greenhouse gases when used.

10 Roads to Removal: Options for Carbon Dioxide Removal in the United States, December 2023, Lawrence Livermore National Laboratory, LLNL-TR-852901. https://roads2removal.org/; Dees et al. (2023) Leveraging the bioeconomy for carbon drawdown. Green Chemistry. https://doi.org/10.1039/d2gc02483g; Sandalow et al. (2020) Biomass Carbon Removal and Storage (BiRCS) Roadmap. https://doi.org/10.2172/1763937

BiCRS can provide an estimated 0.8 to >1 gigaton of CDR annually in the U.S. alone, with costs less than $100 per tonne carbon dioxide.[11] Additionally, BiCRS can improve soil health and water quality[12] and avoid[13] greenhouse gas emissions by using biomass resources that might decay into carbon dioxide, methane, or nitrous oxide, and by producing biomaterials, biochemicals, or biofuels that displace fossil-derived resources.[14]

A BiCRS system uses biomass to remove carbon dioxide from the atmosphere, stores that carbon underground or in long-lived products, and should ideally support food security, rural livelihoods, biodiversity conservation, and other important values.[15]

Examples[16] of BiCRS systems include:

1. Subsurface and burial systems that inject raw or processed biomass (such as sludge or bio-oil) into geologic reservoirs, bury organic carbon underground, or sink organic carbon to the bottom of the ocean.
2. BioEnergy Carbon Capture and Storage (BECCS) facilities that capture the biogenic carbon dioxide exhaust streams from bioenergy or other bioprocessing facilities (e.g., carbon dioxide produced by microbes during fermentation) and store it in geologic reservoirs.
3. Material systems that incorporate biomass carbon or carbon dioxide fixed into carbonates and other building materials, like long-lived wood products or cement
4. Biochar systems that use pyrolysis to heat biomass in the absence of oxygen to produce gaseous, liquid, and solid carbon products that can be used in material and soil applications to durably store carbon and support soil quality.

Currently, early-stage BiCRS projects are largely funded through voluntary carbon markets (VCM) that rely on carbon removal credits issued under protocols. Other funding sources that are important to scale BiCRS systems include compliance markets, tax credits, government procurement, and private investment.[17] Funding is also needed to support research, development, and deployment (RD&D) toward market expansion.

In the VCM, major corporate buyers including Microsoft, Google, and JPMorgan Chase have contracted more than 30 Mt of biomass-based carbon removal since 2022 (including 1.6 Mt in the first half of 2025 alone).[18] BiCRS (chiefly biochar) accounts for more than 95% of all durable carbon removal volumes delivered to date, demonstrating that BiCRS represents the vast majority of delivered CDR and underscoring its readiness for near-term deployment.[19] The majority of those purchased, but as yet undelivered tons come from BiCRS projects associated with bioenergy (BECCS).[20]

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11 Roads to Removal: Options for Carbon Dioxide Removal in the United States, December 2023, Lawrence Livermore National Laboratory, LLNL-TR-852901. https://roads2removal.org/; Dees et al. (2023) Leveraging the bioeconomy for carbon drawdown. Green Chemistry. https://doi.org/10.1039/d2gc02483g; Sandalow et al. (2020) Biomass Carbon Removal and Storage (BiRCS) Roadmap. https://doi.org/10.2172/1763937

12 Malone et al. (2023) Harvested winter rye energy cover crop: multiple benefits for North Central US. Environmental Research Letters. DOI:10.1088/1748-9326/acd708; *Exploring Biomass Carbon Removal and Storage Scenarios for California*. https://www.catf.us/resource/exploring-biomass-carbon-removal-and-storage-scenarios-for-california/

13 We use the terms 'avoided' and 'reduced' emissions in this report as proposed in Gillenwater (2025) https://ghginstitute.org/2025/01/21/what-is-an-emission-reduction-and-when-should-you-avoid-saying-reduced/

14 Roads to Removal: Options for Carbon Dioxide Removal in the United States, December 2023, Lawrence Livermore National Laboratory, LLNL-TR-852901. https://roads2removal.org/

15 Sandalow et al. (2020) Biomass Carbon Removal and Storage (BiCRS) Roadmap https://www.osti.gov/servlets/purl/1763937

16 The emerging BiCRS industry is innovating rapidly, and additional strategies for durable store biomass carbon may be under development, which BiCRS protocols will need to accommodate.

17 *A Policy Framework for Scaling Up Permanent Carbon Dioxide Removal in the United States*. https://www.catf.us/resource/policy-framework-scaling-permanent-carbon-dioxide-removal-united-states/

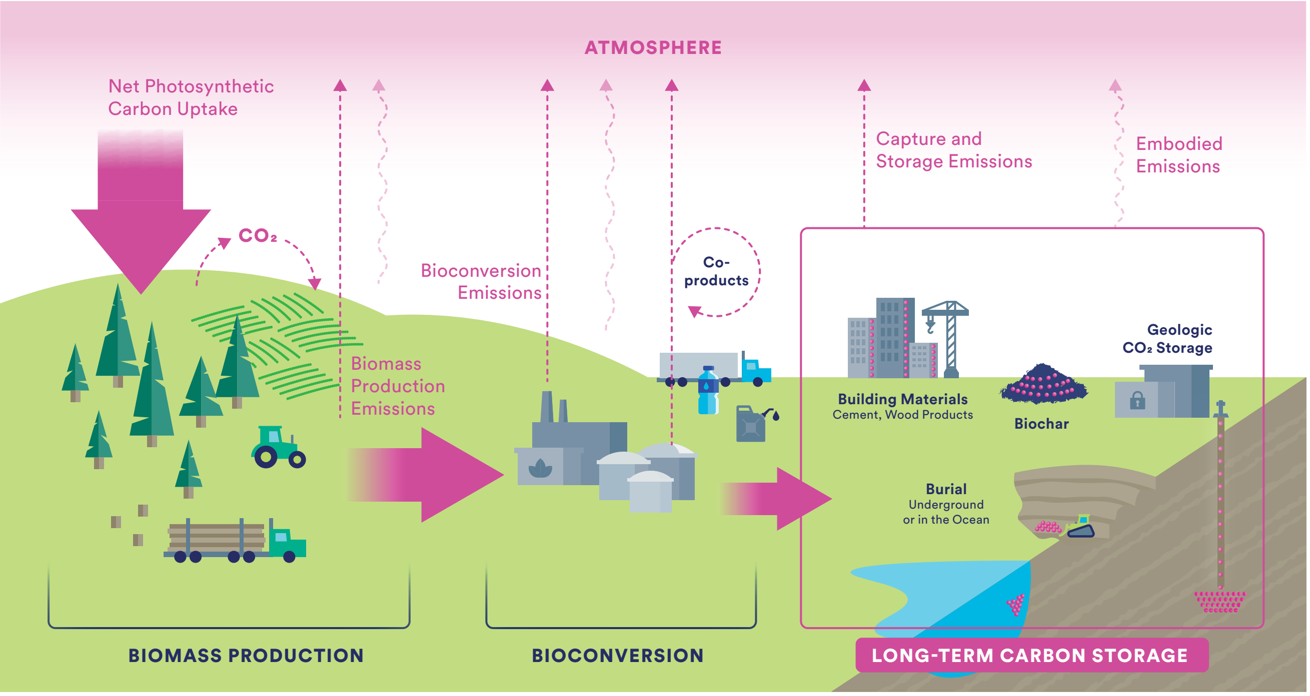
18 https://www.cdr.fyi/

19 2025 Q1 Durable CDR Market Update - Back at Basecamp. https://www.cdr.fyi/blog/2025-q1-durable-cdr-market-update-back-at-basecamp?utm

20 Ibid.

Figure 1. Biomass carbon removal and storage (BiCRS) systems.

Carbon, indicated in pink, is transferred from the atmosphere by plants via photosynthesis and concentrated into biomass. Biomass carbon is then subjected to a bioconversion process that converts it into a storable form, and potentially coproducts like energy or other bioproducts, and the resulting carbon is transferred to durable storage. The full BiCRS system involves multiple sources of emissions that must not exceed the total carbon stored in order to achieve net carbon removal.



Box 1. What is CDR?

Carbon dioxide removal (CDR) refers to interventions that remove carbon dioxide from the atmosphere and store it for a long period of time. CDR differs from direct emissions reductions and techniques to avoid emissions because it addresses carbon dioxide already in the atmosphere.[21] This makes CDR an essential tool for counterbalancing emissions that cannot be technically or economically avoided and for addressing historical carbon pollution. To qualify as CDR, the amount of carbon dioxide removed and stored must exceed the total greenhouse gas emissions across a process lifecycle.

Some purported BiCRS approaches could deliver emissions reductions but fail to achieve a net drawdown of atmospheric carbon dioxide when the entire process lifecycle is considered. Therefore, ensuring that quantification protocols carefully account for all process greenhouse gas emissions is essential to confirm that actual carbon removal has occurred and that resulting BiCRS credits are high-quality.

High-quality credits rely on transparent, science-based methods, independent verification, and measures to ensure that the climate impact would not have occurred without the project. They also require secure, long-term carbon storage and mechanisms to minimize and account for potential loss of stored carbon.

[21] Emissions reductions or avoidance means reducing or eliminating the amount of greenhouse gases entering the atmosphere whereas removal is the withdrawal of greenhouse gases from the atmosphere because of deliberate human activities.

SECTION 2

How were BiCRS protocols assessed?

The number of protocols used to certify carbon removal credits from BiCRS projects has expanded rapidly in the last 5 years. In carbon markets, organizations known as carbon credit registries, CDR companies, or governments create these protocols that BiCRS projects use to calculate carbon removal credits for certification and sale.[22]

CATF assessed how well existing BiCRS protocols ensure that certified carbon credits represent real high-quality CDR. We assembled an interdisciplinary team of scientists, engineers, and economists to evaluate current BiCRS protocols based on an expert elicitation model.[23] The assessment focused on project-scale BiCRS protocols in carbon markets and covered multiple BiCRS systems, including BECCS, bio-oil injection, land and ocean burial, buildings and carbonate materials, and biochar in material and soil applications. Twenty-five publicly available BiCRS protocols, approved for use or under review as of May 1, 2025, were evaluated, providing a snapshot of the rapidly evolving BiCRS market.

We developed a rubric based on four key components of BiCRS systems: 1) biomass production, collection, and transportation, 2) biomass pre-processing and bioconversion, 3) long-term carbon storage, and 4) treatment of the overall system (See Appendix A for methodology details). Across these components, we identified 18 protocol features[24] that are crucial for greenhouse gas accounting and climate integrity. Protocols varied in their approaches to these 18 features, yielding 94 distinct approaches that were scored by experts.

[22] This could include sale/trade in an Emissions Trading System. For example, greenhouse gas removals in the UK Emissions Trading Scheme https://www.gov.uk/government/consultations/integrating-greenhouse-gas-removals-in-the-uk-emissions-trading-scheme

[23] Hemming et al. (2017) A practical guide to structured expert elicitation using the IDEA protocol. Methods in Ecology and Evolution. https://doi.org/10.1111/2041-210X.12857

[24] See Appendix A for feature definitions.

Our analysis focused on features directly tied to greenhouse gas accounting. However, recognizing that responsible BiCRS scaling also depends on thoughtful consideration and management of social and environmental risks and opportunities, we also cataloged how protocols address stakeholder engagement (Box 2), risk mitigation, water impacts, Sustainable Development Goals[25], and other considerations as a basis for future research and protocol improvement efforts (Appendix A).

Box 2. Stakeholder and community engagement

Stakeholder engagement is a crucial step in planning and deploying BiCRS and engagement methods have evolved over time. Best practices suggest tailoring engagement to project scale, complexity, and novelty. Local engagement is always required to comply with ordinances and laws, but broad participation can be considered most valuable for complex or multi-jurisdictional efforts—such as carbon dioxide pipeline networks—where dialogue fosters learning, trust, and adaptive governance. In the absence of engagement, many projects are unlikely to succeed.

Although we did not score protocols on engagement (see Appendix A for unscored features), nine of the 25 protocols reviewed require it. Only three specify a purpose: either to incorporate local knowledge or to avoid reputational, social, or environmental harm. The protocols that require engagement define stakeholders as nearby communities and some also include investors, credit buyers, and Indigenous peoples. Requirements vary from a single advertised meeting to full environmental impact statements; the latter can take months or years. Proactively building trust, transparency, and strong local partnerships is more crucial than ever for the success of BiCRS projects, as information and misinformation now spreads with unprecedented speed and distance.

25 United Nations Department of Economic and Social Affairs. Sustainable Development. The 17 Goals. https://sdgs.un.org/goals

Photo courtesy of Charm Industrial.

SECTION 3

How did the protocols score?

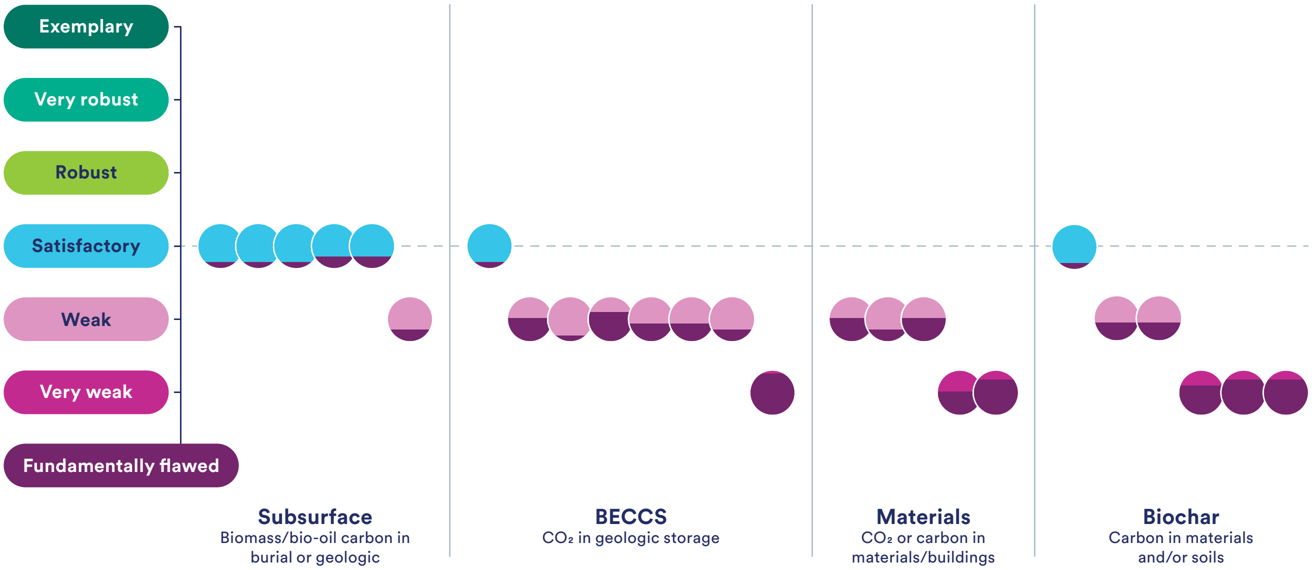
Of the 25 protocols we assessed, 28% scored satisfactory (Figure 2), indicating a solid foundation for the industry to build on. However, there is room for improvement as 78% were rated below satisfactory. Specifically, 12 scored weak, and 6 scored very weak.[26] Each of the protocols reviewed had at least one, and up to seven, fundamentally flawed approaches embedded, indicating a need for improvement across all protocols.

The protocol assessment was technology-neutral (Box 3), but patterns emerged in the scores for four broad BiCRS project categories. Protocols for subsurface storage of organic carbon through land or ocean burial or geological injection scored relatively higher. Five of the six protocols in this category were satisfactory, with only one scoring as weak. In contrast, BECCS protocols scored relatively poorly; only one of the eight protocols was satisfactory. Protocols for storing carbon in materials also scored poorly—among the five protocols evaluated, three scored weak, two very weak, and none were satisfactory or higher. Furthermore, most biochar-based protocols, whether for material or soil amendment use, scored relatively poorly, with only one satisfactory. Some of the key differences in scores across project types relate to how the protocols defined the system boundaries for greenhouse gas accounting (See Cross-cutting Challenge 1).

[26] For context, BiCRS protocols scored better than forest carbon credit protocols, which are at a later stage of development, where only 3% scored satisfactory. https://www.forestcarbonprotocols.org/

Figure 2. Overall protocol scores.

Each point represents an evaluated protocol's median score, indicated by the position along the left axis and the color in the upper portion of the filled circle. The proportion of the point filled in dark purple reflects the number of features that received a median score of 'fundamentally flawed' for that protocol, which range from a minimum of 1 to a maximum of 7 (out of 18 features in total). The protocols were evaluated as of May 1, 2025. Several registries have issued updated versions since that time.



Box 3. The challenges of a technology-neutral approach in policy and standards

Technology-neutral policies and standards for BiCRS offer an important pathway to support innovation, ensure flexibility, and enable the most effective and scalable solutions. By setting clear performance-based criteria rather than prescribing specific technologies or biomass feedstocks, a technology-neutral approach enables a diverse range of BiCRS pathways to compete on outcomes such as carbon intensity and cost effectiveness. This helps avoid picking winners and losers in a rapidly evolving field and supports the growth of both established and emerging technologies across varied regional and market contexts.

However, achieving a technology-neutral approach can also pose challenges. Some systems may require explicit project-specific guidance or tailored greenhouse gas accounting methods to ensure accurate and comparable measurement of climate benefits. Striking the right balance between flexibility and specificity is essential to ensuring beneficial outcomes while supporting BiCRS scaling. Policies must be adaptive enough to accommodate innovation while precise enough to maintain environmental integrity and public confidence.

Photo courtesy of Vaulted Deep.

SECTION 4

What features are crucially important, how did they score, and how can they be improved?

We identified eight of the 18 features as crucially important to greenhouse gas accounting and climate outcomes (Figure 3) through a weighting process and workshop discussion. The features that were weighted as important also generally had the highest number of fundamentally flawed approaches across the population of protocols, suggesting that protocols need to be strengthened to address these important features.[27] The following sections discuss the eight crucial features and provide recommendations for achieving rigor and consistency across protocols. A full list of all evaluated features, the full set of approaches to them, and their scores are available in Appendix A.

[27] The weakest features with the most approaches rated less than satisfactory were Embodied emissions, Crediting period, Treatment of uncertainty, Risk evaluation/mitigation of physical leakage of stored carbon, and Insurance mechanism for reversal. Crediting period, Baseline scenario establishment, Durable storage monitoring period, and Insurance mechanism for reversal did not have any approaches that scored higher than satisfactory. The top features listed in order of importance based on expert scores were: MMRV of the storage site, Biomass production emissions, Durable storage monitoring period, Crediting period, Insurance mechanism for reversal, Tracking and verifying biomass carbon, Risk evaluation/mitigation of physical leakage of stored carbon, Treatment of uncertainty, Embodied emissions, and Alternative fate of biomass. The top features with the highest number of fundamentally flawed approaches across protocols were: Durable storage monitoring period, Treatment of Uncertainty, Alternative fate of biomass, Tracking and verifying biomass carbon, Embodied emissions, MMRV of the storage site, and biomass production emissions.

Figure 3. The highest-scoring approach and recommendations for eight crucial features.

Summaries of the highest scoring approaches to the eight crucial features discussed are presented, along with their score and recommendations for improvement. In cases where the median scores were tied for highest between approaches, we present the approach with the greatest mode in this table. Additional information is available in the appendix, including summaries and scores for all evaluated approaches in Figure 5 and full descriptions in the supporting data table.

Crucial Feature	Highest Scoring Approach in Existing Protocols	Recommendation
#1 Biomass production emissions	Very Robust — Full inclusion and explicit quantification for both purpose-grown and other (e.g., waste) biomass.	Account for all biomass production emissions in protocols to the maximum extent possible
#2 Alternative fate of biomass	Robust — Regional/market-based analysis that biomass is regionally abundant and not used in existing markets.	Standardize the treatment of the alternative fate of biomass by requiring transparency, empirical data, and regional specificity. Quantify and report avoided emissions separately from carbon removal
#3 Facility baseline scenario establishment	Satisfactory — Project-specific and scientifically justified based on modeling or carbon behavior assumptions.	Standardize the treatment of the BiCRS facility baseline across protocols, especially regarding retrofitting existing facilities for BiCRS
#4 Allocation of emissions to coproducts	Satisfactory — Full allocation of emissions to the CDR process regardless of coproducts.	Appropriately account for coproduct emissions in the quantification of CDR based on standard best practices
#5 MMRV of storage	Robust — Direct monitoring, including leak detection and explicit response mechanisms.	Implement long-term, robust approaches to MMRV of carbon storage consistently tailored to centralized and decentralized storage reservoirs
#6 Insurance mechanism for reversal	Satisfactory — Default buffer pool contribution of 0-6% based on relevant storage, range includes all types.	Require buffer pools and tie the size of the pool directly to the risk associated with the carbon storage approach
#7 Treatment of uncertainty	Very Robust — All sources are reported with sensitivity analysis. Variables with <1% effect on removals are excluded; others incorporated into removal quantification.	Standardize uncertainty quantification in BiCRS protocols while maintaining flexibility to accommodate emerging technologies and methodologies
#8 Embodied emissions	Very Robust — Included for all equipment and allocated over a specified timeline; quantified at the project level.	Account for embodied emissions for all BiCRS project types and across the full life cycle

Crucial Feature 1: Biomass production emissions

This feature encompasses emissions from the production and collection of biomass. Biomass production emissions include fertilizer production and application, fuel for farm equipment and biomass transport, and soil carbon released through land management and change. These emissions arise from different types of biomass resources, including 1) plants intentionally cultivated for BiCRS (purpose-grown crops) such as corn, winter rye, switchgrass, and poplar, and 2) waste, residue, or byproduct biomass resources (herein wastes) from managed lands, existing agrifood systems, and industrial processes, such as forest residues, crop residues, animal manure, sawmill residues, food processing waste, municipal solid waste, and nonrecyclable paper. This feature is distinct from questions about the alternative fate of biomass (and related avoided emissions), which are addressed in Crucial Feature 2.

Clear accounting of biomass production emissions is important in BiCRS protocols. Accounting for these emissions can generate additional positive outcomes in land management systems. For example, including biomass production emissions in BiCRS protocols can incentivize climate-smart[28] agriculture and forestry practices that reduce emissions. As a result, producers can gain experience with these practices, making them less likely to overestimate the costs and labor involved, and more likely to adopt practices broadly for other products, including food and fiber.[29] Rigorous accounting will also drive innovation in measurement, monitoring, reporting, and verification, which can serve as a model for the food and fiber markets. Some biomass production emissions are difficult to measure, including those from direct and indirect land use change (Box 4), but excluding them can lead to over-crediting, damage the credibility of BiCRS markets, and greatly reduce public and private support, as the bioenergy sector learned over a decade ago.

However, applying rigorous accounting to upstream emissions in systems with waste biomass from diverse and distributed sources presents unique challenges that warrant careful consideration. For example, some wastes can be difficult to track and therefore difficult to attribute emissions to a specific production system, may involve materials with sunk environmental costs with no consensus definition of newly generated versus legacy waste, and may induce additional demand that could generate emissions when diverted from existing uses.[30] Fully exempting these emissions from system boundaries might distort the market and risk overproduction or reliance on these biomass resources without regard to their lifecycle emissions. Comprehensive upstream accounting could signal to project developers and policymakers that not all waste biomass pathways are universally carbon-neutral and should be assessed in the same rigorous manner as other systems, but this may not be practical for some waste biomass BiCRS systems.

Protocols vary in how they treat biomass production emissions, leading to differences in greenhouse gas accounting robustness and credibility. Protocols that include all emissions from biomass production scored very robust. Satisfactory protocols either conditionally include emissions from waste biomass or use conservative default factors for purpose-grown feedstocks.

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28 World Bank Group. Climate-Smart Agriculture. https://www.worldbank.org/en/topic/climate-smart-agriculture; North Carolina State University. What is Climate Smart Forestry? A Brief Overview. https://content.ces.ncsu.edu/what-is-climate-smart-forestry-a-brief-overview

29 Liebert et al. (2025) Not as hard as it seems? Labor challenges and opportunities for agroecological practices in the United States. https://doi.org/10.1007/s10460-025-10796-z

30 Nordahl et al. (2024) Carbon accounting for carbon dioxide removal. DOI: 10.1016/j.oneear.2024.08.012

Weak protocols leave the decision of whether to include or exclude biomass production emissions to the project's discretion because emissions might be allocated to coproducts like bioenergy, food, or fiber (see Crucial Feature 4 for coproduct emissions allocation discussion). Protocol approaches scored very weak or fundamentally flawed, respectively, if boundaries were not clearly specified or biomass production emissions were not explicitly addressed. Accounting for biomass production emissions consistently over the BiCRS project lifetime, using conservative default values where data are limited and updating emissions as measurement capabilities improve, could avoid both near-term over-crediting and long-term lock-in of emissions-intensive biomass feedstock systems. Applying approaches to accounting for biomass production emissions consistently across biomass types, or at least with clear justification where exclusions or conditional treatments are reasonable, could help avoid shifting emissions to unregulated markets.

Recommendation 1: Account for all biomass production emissions in protocols.

Protocols should account for all biomass production, collection, and transport emissions to the extent possible to ensure that BiCRS credits represent genuine net carbon removals rather than shifting emissions elsewhere in the supply chain. Waste, residue, or byproduct biomass emissions from diverse and distributed sources may be within the BiCRS system boundary (see Cross-cutting Challenge 1) but may not be possible to quantify, trace, or allocate, and may require conditional treatment or conservative default values.

Box 4. Land use change and BiCRS

BiCRS systems that rely on dedicated feedstock production may cause unintended changes in land use. Ideally, these changes would be positive for climate mitigation, but that isn't always the case. Directly converting carbon-rich areas like forests and grasslands for BiCRS feedstock production could undermine or negate the carbon benefits of BiCRS. Indirect land use change can also undermine climate benefits by driving the conversion of forests and grassland if BiCRS feedstock production displaces food production and shifts its expansion into these ecosystems.

BiCRS protocols can account for direct land use change since it can be observed, monitored, and managed[31] but indirect land use change cannot be directly or precisely measured. It is a consequence of market-mediated behavior tangled with many other drivers that influence agricultural prices and production. As such, indirect land use change has been assessed only through models that simulate the agricultural, economic, and environmental aspects of feedstock supply and demand. Indirect land use change can result in both positive and negative economic and environmental impacts, arising from the intensified use of existing agricultural land, with complex temporal and spatial dynamics that depend on location, land use history, management practices, and overarching public policies on land use governance. As a result, estimates of indirect land use change are highly uncertain, and there is little agreement in the scientific literature.

[31] In practice, one would like to see beneficial land use changes occur as a result of BiCRS systems.

Despite the challenges, BiCRS protocols can reduce land use change risk in several ways, including by promoting activities that improve feedstock management and yields and pushing the industry toward sustainable intensification; relying on and improving the use of waste and residues; adopting sustainable practices, such as climate-smart agriculture, multi-cropping; and limiting land use expansion to marginal, degraded, or restored land. Broader policies that govern land use and aim to reduce negative land use changes, or that target local drivers of deforestation, can also reduce risk. In practice, encouraging the positive and penalizing the negative potential outcomes from indirect land use change requires macro-scale integrative perspectives on land use and associated policies that are difficult for individual project-level initiatives to have a meaningful impact on. This is one area where funding for academic RD&D may help advance the entire BiCRS industry.

Crucial Feature 2: Alternative fate of biomass

This feature describes whether and how the protocol requires BiCRS developers to account for what would have happened to the carbon in the biomass without the BiCRS project. The true climate value of a project depends not only on how much carbon is stored but also what would have happened to the biomass otherwise. The language used to describe the alternative fate of biomass is inconsistent across protocols; they refer to this feature as both the counterfactual and the baseline (we use the latter). The biomass baseline could involve a portion of biomass carbon that would otherwise be durably stored in ecosystems without any intervention, thus reducing the climate impact of the project, or alternatively, emitted as carbon dioxide, methane, or nitrous oxide thereby enhancing the climate value of the project.

Because the climate value of BiCRS projects depends on the alternative fate of biomass, a credible biomass baseline is central to assessing additionality[32] and to avoiding over- or under-crediting. Many BiCRS systems may deliver both avoided emissions, such as methane or nitrous oxide that would otherwise be released from waste biomass, along with the primary output of durable carbon removals. Making a clear distinction between avoided and removed emissions enables more accurate valuation and increases transparency and trust in the climate impact of BiCRS projects. Avoided-emissions baselines are usually hypothetical and inherently uncertain. In contrast, carbon removal achieved by BiCRS systems represents a physical, directly quantifiable process that does not rely on such baselines and therefore provides a more robust accounting basis.

Because of these issues, reporting biomass baselines separately from carbon removals ensures that both are appropriately measured and incentivized. Protocols that incorporate a project-specific baseline analysis approach or a regional- or market-based demonstration approach scored robust. Protocols that do not assess the alternative fate of biomass, or that assume all biomass is waste or would have decayed, scored fundamentally flawed or weak, respectively.

Recommendation 2: Standardize the treatment of the alternative fate of biomass by requiring transparency, empirical data, and regional specificity. Quantify and report avoided emissions separately from carbon removal.

Given that biomass baseline emissions cannot be measured, their calculation should be transparent, based on prior emissions measurements to the extent possible, and locally grounded to account for regional variation. If the biomass baseline is determined to result in avoided emissions, those emissions should be quantified but reported separately from carbon removals, meaning they should not be accounted for in the quantification of net carbon removal.

32 The demonstration that CDR would not have occurred in the absence of the carbon credit.

Crucial Feature 3: Facility baseline scenario establishment

Building on the concept of the biomass baseline, this feature describes how protocols[33] define what would have happened regarding the BiCRS facility without the BiCRS project and associated carbon removal credit revenues. Because the baseline determines whether carbon removal is truly additional, it is central to credit integrity and perverse incentives. This feature is particularly relevant to BiCRS facilities that produce non-CDR products such as biofuels that generate revenue from those products.

The strongest approaches establish baselines that are scientifically justified, reflect current market and policy conditions, and can be updated as those conditions change. Static or overly simplified baselines were seen as risky in a changing bioeconomy, where biomass resource use can shift quickly in response to price signals and market demand. Transparent documentation of baseline assumptions, empirical data support, and periodic reassessment were discussed as an ideal.

Protocol approaches that apply different baselines for retrofits at existing facilities with carbon capture and storage (CCS)[34] versus new-build facilities that incorporate durable carbon storage from the outset or that fail to clearly define a baseline scored low. For example, adding CCS to an existing pulp and paper mill that already combusts wood residues for on-site energy does not necessarily constitute carbon removal if the facility was previously emitting biogenic carbon dioxide under a baseline consistent with biomass combustion; in such cases, the addition of CCS may only represent a reduced emission relative to the pre-existing system, rather than a true net removal of carbon from the atmosphere. More generally, the assumption that retrofitting CCS onto an existing bioconversion facility automatically results in CDR can lead to systematic over-crediting by ignoring upstream biomass production and logistics, the underlying bioconversion process, and the counterfactual fate of biomass-derived carbon. Protocols that quantify removal using narrow system boundaries around the CCS process, while excluding emissions from biomass growth, harvest, transportation, and processing, risk reporting reduced emissions rather than true atmospheric carbon removal.

Recommendation 3: Standardize the treatment of the BiCRS facility baseline across protocols, especially regarding retrofitting existing facilities for BiCRS.

Current approaches vary widely in how they treat new-build BiCRS facilities vs. retrofitted bioconversion facilities. Protocols should standardize their treatment of baselines across these different BiCRS project types and require transparent documentation of baseline assumptions, empirical data support, and periodic reassessment.

Crucial Feature 4: Allocation of emissions to coproducts

This feature describes approaches to properly assigning emissions burdens[35] in BiCRS systems that produce multiple products. BiCRS projects that generate coproducts such as bioenergy, biochemicals, or biomaterials can offer lower emission alternatives to fossil-derived counterparts and possibly generate revenue to improve project economics. But allocating emissions among coproducts introduces accounting complexities that must be treated responsibly, and many protocols offer little guidance on best practice.

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[33] The protocols' approaches to this feature were grouped into five approach categories: 1) Retrofit vs. new build differentiation. Defines separate baselines for retrofitted facilities versus new facilities, with specific rules governing timing and emissions attribution. 2) Static or common counterfactual scenario. Assumes a generic 'no-project' baseline where infrastructure and project activities do not occur. Often considers zero emissions or no carbon storage as the default. Generally applied to a new facility. 3) Contextual, market- or material-based baselines. Establishes baselines based on comparison with conventional market practices or similar functional alternatives (e.g., using Environmental Product Declaration). 4) Scientifically justified baselines with Validation and Verification Body (VVB) expert review. Baseline based on scientific modeling or carbon behavior assumptions, subject to third-party or expert review, often limited to a fraction of the claim. 5) Not discussed or ambiguous. The protocol does not define a baseline or only implies one indirectly without formal establishment.

[34] For example, existing corn ethanol facilities adding carbon capture and storage (CCS), existing biogas facilities adding CCS (upgrading to biomethane or not), existing pulp and paper mills adding CCS, and existing biomass power facilities adding CCS. See Dees et al. (2023), Leveraging the bioeconomy for carbon drawdown, DOI: 10.1039/D2GC02483G for some examples.

[35] Such as allocation based on mass.

To address these challenges, prohibiting allocation of any emissions to coproducts has been proposed as the most robust option.[36] Best practices for lifecycle assessments of BiCRS technologies[37] recommend a hierarchy of allocation strategies, although carbon markets do not uniformly adopt this hierarchy. The top recommendation in recent best practices literature[38] is to avoid allocation entirely by breaking down the system into sub-processes that handle each coproduct separately. In tightly integrated systems where separation is not possible, the next level is to allocate emissions based on physical relationships, such as by the fractions of mass or energy that end up in each coproduct. Only when these options are impossible are other allocation strategies suggested, such as those based on economic value.

Economic allocation can be particularly problematic in BiCRS systems, where prices of both feedstocks and products are likely to increase significantly over time. Many BiCRS projects are targeting waste biomass, which currently has no monetary value and thus would be allowed zero emissions burden under some common frameworks. On the products side, the current market value of removed carbon is small relative to other coproducts, so projects may justify allocating a fraction of their emissions to coproducts that are sold in unregulated markets where emissions burdens are not penalized. Additionally, coproducts from BiCRS systems sometimes substitute fossil-derived products thereby avoiding fossil emissions, which depend on an assumed counterfactual in which fossil jet fuel would otherwise have been burned. For example, BiCRS systems can produce sustainable aviation fuel. Such emissions are expected to decline as the aviation sector decarbonizes, and recent best practices literature[39] recommends avoided emissions associated with co-product substitution should be accounted for separately and transparently (similar to avoided biomass emissions). This helps ensure that any avoided fossil emission benefits are credited in ways that reflect the evolving carbon intensity of the sectors that BiCRS coproducts displace, rather than locking in assumptions that become outdated as alternatives emerge. Shifting emissions burdens away from the BiCRS process can inappropriately inflate the magnitude of carbon removal, especially if the burden is shifted to products operating in markets without emissions restrictions. In markets where coproducts are subject to emissions regulations or carbon pricing, allocation of emissions to coproducts may be appropriate. Such allocation may warrant reassessment as emissions regulations change over time to ensure protocols remain robust and do not under- or double-count emissions.

Approaches that deduct all emissions associated with the process from the calculation of CDR, regardless of what other products the system produced, scored robust since this approach is most likely to avoid over-crediting. Approaches that allow project developers' discretion in choosing an allocation method (some, all, or none of the BiCRS process emissions allocated to the CDR), sometimes requiring transparency or justification, or those that allow allocation using standardized principles, scored satisfactory. Approaches that provide no explicit guidance on allocation scored very weak.

Recommendation 4:
Appropriately account for coproduct emissions in the quantification of CDR based on standard best practices.

Protocols should require coproduct allocation methods that reflect best practices for BiCRS systems, adopt a consistent hierarchy of allocation strategies, and fully justify any deviations from it. Clear and consistent rules reduce the risk of shifting emissions burdens to unregulated coproducts. The allocation method should not be decided by the BiCRS project developer, but by the BiCRS protocol to ensure a level playing field for all BiCRS pathways.

36 Nordahl et al. (2024) Carbon accounting for carbon dioxide removal. DOI: 10.1016/j.oneear.2024.08.012

37 U.S. Department of Energy (2025) Best Practices for Life Cycle Assessment (LCA) of Biomass Carbon Removal and Storage (BiCRS) Technologies https://www.energy.gov/fecm/best-practices-life-cycle-assessment-bicrs

38 Ibid.

39 Ibid.

Crucial Feature 5: Measurement, Monitoring, Reporting, and Verification (MMRV) of storage

This feature addresses how storage durability[40] is measured, monitored, reported, and verified. MMRV includes collecting data on the carbon stored, such as using gas monitoring to check for leaks, compiling the collected data into a report, and using an independent third party to verify the reported data to ensure the carbon is stored durably as claimed. Given that the minimum relevant timescales for durable storage range from several decades to centuries, long-term, robust approaches to MMRV of carbon storage sites are essential.

Existing feasible options for MMRV may differ across project types. For example, the logistics of monitoring a centralized geologic storage location are very different from monitoring highly dispersed carbon storage, such as in cement/concrete, durable wood products in construction, and biochar in soils. While there is strong evidence from many existing subsurface gas reservoirs that high-quality geologic sequestration sites can store carbon dioxide for millennia, other BiCRS storage strategies, such as undigested organic carbon injection, have few existing analogues and therefore involve more uncertainty.[41] As for biochar, limited evidence suggests that degradation rates differ across feedstocks and production conditions, and that interactions with environmental factors also affect the durability of biochar carbon storage in specific soil types and locations.[42] Similar questions arise for other storage options, from buildings or materials to biomass burial in land or ocean settings.

Actual or perceived conflicts of interest for third-party verification bodies can be a concern when verifiers are hired at the discretion of a project developer, even from a pre-approved population of certified entities. While verifiers are not directly compensated per unit of BiCRS carbon credit, if they are paid by project developers, they could face pressure to approve weak projects or risk being passed over for future projects. This concern might be addressed by implementing a system[43] to manage the selection and assignment of certified verifiers to BiCRS projects, ensuring an appropriate level of independence.

All the evaluated protocols do require third-party verifiers, and projects generally are allowed the discretion to select them. Top-scoring approaches require direct environmental monitoring, frequent inspections, and explicit response mechanisms for reversals or leaks, often extending beyond the project's operational life. Most approaches provided some level of detailed guidance on approaches to MMRV, but those that lacked clarity and/or explicit requirements to monitor the storage of carbon scored as fundamentally flawed.

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40 Durable storage is used in this report to describe storage in engineered reservoirs that can reasonably be expected to last for at least 100 years. Some BiCRS systems achieve permanent storage, which we consider a subset of durable storage. We consider permanent to mean BiCRS techniques with a demonstrated low risk of physical reversal for at least 1,000 years in their storage reservoir.

41 Alcalde, J, S. Flude, M. Wilkinson, G. Johnson, K. Edlmann, C. E. Bond, V. Scott, S.M.V. Gilfillan, X Ogaya, and R. S. Haszeldine. 2018, Estimating geological carbon dioxide storage security to deliver on climate mitigation, Nat.Commun: 9(1), 1–9. DOI: 10.1038/s41467-018-04423-1; Dees, J.P., W.J. Sagues, E. Woods, H.M. Goldstein, A.J. Simon, D.L. Sanchez. 2023. Leveraging the bioeconomy for carbon drawdown Green Chem, 25:2930-2957, DOI: 10.1039/D2GC02483G; Intergovernmental Panel on Climate Change (IPCC), Carbon dioxide capture and storage (IPCC special report; prepared by Working Group III of the Intergovernmental Panel on Climate Change)), ed. B. Metz, et al. 2005, Cambridge, UK and New York, NY, USA: Cambridge University Press; (Available at https://www.ipcc.ch/report/carbon-dioxide-capture-and-storage/) 442 p.

42 Schmidt et al. (2025) Biochar Permanence—A Policy Commentary. doi: 10.1111/gcbb.70092

43 As an example of a system that manages independent verifiers, the Regional Greenhouse Gas Initiative (RGGI) requires projects must be verified by a state-accredited independent verifier, requires pre-engagement conflict of interest disclosures before a verifier works on any project, and RGGI maintains a central registry of approved verifiers. https://www.rggi.org/allowance-tracking/offsets/verification-process

Recommendation 5:
Implement long-term, robust approaches to MMRV of carbon storage consistently tailored to centralized and decentralized storage reservoirs.

Protocols should require projects to adopt long-term, scientifically rigorous approaches to MMRV of the carbon storage site, including provisions for detecting and mitigating reversals, where appropriate. For projects generating products with decentralized storage across many small, but similar sites, a statistical approach to MMRV may be sufficient provided it is also scientifically rigorous. Continued RD&D is needed to understand the true durability of various storage forms, especially biochar, buried biomass, and injected bio-oil and bio-slurry. Additionally, independent third-party verifiers should not be selected and hired by project developers or buyers to avoid real or perceived conflicts of interest.

Crucial Feature 6: Insurance mechanism for reversal

This feature refers to the protocol's approach to ensure that any unplanned losses of stored carbon underpinning BiCRS carbon credits can be compensated. Approaches to this feature can help address the questions about storage duration mentioned above, as well as other system uncertainties. A typical approach in carbon markets involves maintaining a buffer pool, which functions as a reserve account of credits sourced from many different projects, that can be drawn on if issued carbon credits for any individual project(s) are compromised.

This feature is crucial to market credibility, yet there is very little consistency among the protocols. We characterized 12 approaches to this issue across the 25 protocols, the highest number of approaches cataloged for any of the features. In general, approaches that neglected this issue entirely were rated fundamentally flawed, those that assumed regulatory oversight was sufficient were rated weak, and those that require risk-based discounts or buffer pools (ranging from 0% to 25%) were rated satisfactory. Approaches that scored highest require projects to surrender a pre-determined percentage of credits to a buffer pool, with value tied to storage risk. The expert panel noted that BiCRS protocols focused on specific technologies, such as carbon dioxide storage in cement products, may have a legitimate scientific rationale for not needing a buffer pool once the carbon is chemically bound in mineral form.

Recommendation 6:
Require buffer pools and tie the size of the pool directly to the risk associated with the carbon storage approach.

Except for a few technology-specific cases (such as carbon dioxide injected into geologic storage reservoirs), BiCRS projects should surrender a pre-determined percentage of credits to a buffer pool, with the value tied to the project's storage risk.

Crucial Feature 7: Treatment of uncertainty

This feature describes the requirements for handling inherent uncertainty in the BiCRS project net removal quantification. This covers uncertainty quantification and reporting, including process emissions and how minimal-emission contributors may be excluded or identified through sensitivity analysis. Protocols that do not adequately account for uncertainty may underestimate biomass carbon losses and greenhouse gas emissions from the system, thereby overpromising actual carbon removals.

Like any emerging technology, BiCRS can involve significant uncertainty in projecting and quantifying mass flows and energy requirements in operating a facility. Additional uncertainties arise in greenhouse gas fluxes in the ecologically complex and difficult-to-measure forest and agricultural systems where biomass used in BiCRS is produced and sourced, as well as in carbon losses during biomass transport and storage, in the coproduct lifecycle, and in the durability of the carbon storage itself.

A lack of consistency and clarity in how protocols assess and manage uncertainty risks over-crediting when uncertainties in carbon accounting, biomass sourcing, conversion efficiency, baseline establishment, or permanence and reversal quantification are underestimated or inconsistently applied. Transitioning towards standardized methodologies can mitigate this risk. Standardizing measurement boundaries, establishing conservative discount factors for uncertainties, and implementing minimum data quality standards could reduce over-crediting risk and strengthen both BiCRS credit integrity and the broader market. Qualitative (e.g., empirical studies that use questionnaires or interviews[44]) and quantitative (e.g., sensitivity analysis, scenario design, or simulation[45]) approaches exist to characterize uncertainty and provide reasonable discount factors that protocols could incorporate, reducing the risk of selling more carbon removal than is ultimately achieved. However, standardization must be balanced to avoid excessive rigidity, which poses a dual threat. Rigid protocols can stifle innovation by locking the market into suboptimal technologies. Mandating a single approach for carbon measurement or biomass pretreatment may exclude newer, more cost-effective, or efficient alternatives, hindering the innovation needed for BiCRS to scale and achieve cost competitiveness. Moreover, large-scale societal and market recognition of the value of stabilizing and sequestering biomass carbon is a relatively recent development, and the BiCRS landscape remains highly dynamic. It is therefore likely that disruptive technologies and entirely new BiCRS pathways will emerge that must be accommodated by existing protocols if the field is to remain credible and scalable.

Across existing protocols, there is significant variation in how uncertainties are assessed and managed. Few protocols characterize these uncertainties robustly. Some approaches specify de minimis thresholds of 1% to 10%, below which uncertainty quantification can be neglected and above which removals are discounted, though the rationale for these values is sometimes unclear or poorly documented. Top-scoring approaches require all variables and uncertainties to be reported, use sensitivity analyses, and include procedures to incorporate uncertainty into results.

Recommendation 7:
Standardize uncertainty quantification in BiCRS protocols while maintaining flexibility to accommodate emerging technologies and methodologies.

BiCRS protocols should adopt standardized measurement boundaries and conservative discount factors for uncertainties, while remaining flexible to accommodate approaches that better characterize and hopefully reduce uncertainty as science and technology advance. One approach could be the introduction of a quantification uncertainty buffer pool that would hold aside credits based on conservative default factors; if and when measurement certainty improves, credits could be released for sale on the market. Protocols should balance rigor with adaptability when addressing uncertainty to support high-quality credits, while driving technological and cost improvements in BiCRS projects.

Crucial Feature 8: Embodied emissions

This feature describes off-site greenhouse gas emissions required to manufacture equipment and other inputs for a BiCRS system. These can include the embodied emissions required to produce fertilizers, fuel, and equipment for growing and transporting biomass, as well as the emissions embodied in the equipment, buildings, and other materials in a BiCRS facility. Whether these embodied emissions are included in the system boundary is an issue that is particularly relevant for retrofit BiCRS facilities. Several protocols exclude embodied

44 Habibi et al. (2023) Towards facing uncertainties in biofuel supply chain networks: a systematic literature review. Environ Sci Pollut Res Int. doi: 10.1007/s11356-023-29331-w

45 U.S. Department of Energy (2025) Best Practices for Life Cycle Assessment (LCA) of Biomass Carbon Removal and Storage (BiCRS) Technologies https://www.energy.gov/fecm/best-practices-life-cycle-assessment-bicrs

emissions from existing facilities, so that only the new equipment for carbon capture is considered. While this approach encourages the deployment of carbon capture technology at existing facilities, if a facility has a high carbon footprint, those emissions (including embodied emissions) should be fully offset before carbon removal credits begin to accrue.

The most robust approaches in the protocols include embodied emissions of both retrofitted- and new-build-BiCRS facilities and provide methods to amortize those emissions over a specific timeframe or the facility's operational life. Approaches that do not discuss these emissions were considered fundamentally flawed, while those that exclude emissions associated with existing facilities or require lifecycle analysis without explicit guidance on how to treat them were considered weak.

Recommendation 8:
Account for embodied emissions for all BiCRS project types and across the full life cycle.

Protocols should account for embodied emissions across the full lifecycle of the project, which would include embodied emissions for existing facilities retrofitted for BiCRS and for new builds. Protocols should also specify methods to amortize those emissions over a specific timeframe or the life of the facility.

Photo courtesy of Charm Industrial.

SECTION 5

What cross-cutting challenges need to be addressed across all BiCRS protocols?

Based on the crucial features outlined above, we identified gaps or inconsistencies in current protocols that need to be addressed to ensure both climate outcomes and market integrity. Below, we highlight the challenges to addressing these areas and make recommendations to strengthen the credibility and scalability of BiCRS systems.

Cross-cutting Challenge 1: System boundaries

Current protocols vary widely in which emission sources are included within project system boundaries (Figure 4), reflecting fundamental differences in the underlying carbon accounting framework's goals, including whether to address questions related to quantifying the net outcome of all fluxes of carbon uptake and emissions across the entire project lifecycle (comprehensive boundaries) or just the greenhouse gas emissions associated with the new activity of capturing and storing carbon (narrow boundaries). Differences in system boundary choices reflect different greenhouse gas accounting goals. When protocols make these goals and boundary choices explicit, it can help avoid misinterpreting credits derived under narrow boundaries as equivalent to those under comprehensive boundaries.

The way system boundaries are handled across existing protocols tend to correlate with the BiCRS project type. Protocols for subsurface storage of biomass or bio-oil generally have more comprehensive lifecycle boundaries and are typically designed for purpose-built projects rather than bioconversion facility retrofits. For BECCS protocols, the system boundaries are narrower. All BECCS protocols account for emissions associated with adding carbon capture and storage to existing bioenergy facilities (e.g., ethanol refineries, pulp and paper mills), but many exclude upstream emissions from biomass sourcing, preprocessing, and bioconversion, and sometimes leave allocation of emissions to coproducts to the project's discretion. By treating these emissions as part of the baseline or outside system boundaries, and therefore not deducting them from the carbon stored, calculated removals can be inflated. In extreme cases, some protocols could certify removals from projects even when net emissions are positive.

In general, across the population of protocols, purpose-built projects are more likely to have expansive system boundaries that include emissions from biomass production and processing, whereas retrofit projects associated with existing industrial processes often have narrow boundaries and more flexible approaches to allocating emissions among coproducts. Protocols associated with the storage of carbon dioxide or carbon in materials and/or buildings have similar narrow boundaries as BECCS. Biochar project protocols are split; some require more expansive system boundaries, and others allow for a narrow view of the system (e.g., ignoring emissions associated with biochar application). These differences could result in different estimates of carbon removal for the same project depending on which protocol is applied.

The importance of these differences becomes clear when comparing how current protocols treat otherwise similar BiCRS systems. Consider a facility that grows biomass, transports it, and converts it into biochar and carbon dioxide with bio-oil combusted on-site to provide process heat. Because the primary product is a carbon removal credit, the project is typically assigned all upstream emissions (cultivation, fertilizer use, harvesting, and transport) as well as all on-site process emissions (pyrolysis and energy generation).

In contrast, a pulp and paper mill that grows biomass, transports it, and converts it into paper products while capturing biogenic carbon dioxide—derived from combusting black liquor on-site for heat and energy—is commonly allowed to allocate nearly all upstream and on-site emissions to its commercial paper products. Under many protocols, the carbon removal credit from captured carbon dioxide is burdened only with the incremental emissions associated with the capture system itself, not the emissions from growing the trees, transporting them, or operating the mill.

This discrepancy has meaningful consequences for BiCRS deployment. The existence of protocols with narrow boundaries for retrofits may systematically disadvantage pathways that are purpose-built for carbon removal while conferring an accounting advantage to facilities whose primary output is a commercial product. Two facilities performing fundamentally similar physical actions on biomass can report dramatically different net removals solely because one is labeled as a "carbon removal plant" while the other is a "product manufacturer with CCS." Moving from narrow to comprehensive system boundaries could correct this distortion by ensuring that all BiCRS pathways are evaluated on the same atmospheric basis: carbon enters the accounting framework at the point of biological carbon dioxide capture and remains within the system boundary until it is durably stored or returned to the atmosphere. This could help prevent over-crediting and establish a level playing field between purpose-grown biomass systems and systems that rely on industrial co-products or legacy infrastructure.

Figure 4. Emission sources included in greenhouse gas accounting vary across protocols, reflecting different system boundaries

Rows represent individual evaluated protocols grouped by project type. The presence of colored bars indicate whether relevant emissions sources are included (full bar), partially or conditionally included (half bar), or excluded (no bar), either explicitly or likely in practice because they are not discussed or optional and unfavorable. Protocols with comprehensive system boundaries include all relevant emissions sources (all bars filled in), whereas those with narrow system boundaries include fewer sources. The protocols were evaluated as of May 1, 2025. Several registries have issued updated versions since that time.

A central reason these discrepancies arise is that protocols mix two fundamentally different system-boundary frameworks. First, when accounting under comprehensive system boundaries,[46] the reference frame is the concentration of carbon dioxide in the atmosphere. The system boundary extends from photosynthesis through biomass cultivation, transport and processing, emissions from the new activity, all upstream emissions the new activity depends upon, and any downstream emissions. This approach treats purpose-grown and waste biomass, and purpose-built and retrofit systems, consistently. Comprehensive system boundaries align with an atmospheric perspective and enables equivalent comparisons across BiCRS pathways.

[46] Nordahl et al. (2025) Carbon accounting for carbon dioxide removal. OneEarth. doi:10.1016/j.oneear.2024.08.012

An alternate frame, accounting under narrow system boundaries, uses the existing industrial activity as the reference frame and only includes emissions attributable to the new activity enabling CDR. This approach excludes upstream processes such as biomass cultivation or previous uses of co-located facilities. For example, emissions from biomass cultivation and use may be excluded at retrofitted corn ethanol refineries or pulp and paper mills with carbon capture and storage. In such cases the credits may actually represent an emissions reduction rather than a removal, since this method is intended to quantify the net carbon benefit of a new activity relative to an existing activity. Narrow system boundaries therefore draw a more easily measured boundary around only the incremental changes due to the project and can lead to over-crediting.

Another distinction applies to BiCRS pathways using waste biomass.[47] Emissions from producing those waste materials are typically excluded in protocols. Using waste biomass has many advantages, including avoiding decomposition emissions associated with the biomass baseline. If wastes were priced or taxed reflecting their upstream emissions, then the assumption that waste has no production or sourcing emissions burden would be logical. However, when protocols exclude waste emissions from the system boundary and those emissions are not allocated elsewhere, they risk creating high demand for waste. Rising demand for waste biomass introduces a modest but non-zero risk of overproduction, overharvesting, or diversion from other important uses.

Greenhouse gas accounting that uses both comprehensive and narrow system can be logical, but represent different types of projects. Moreover, challenges remain, especially in determining the biomass baseline, and quantifying waste biomass emissions and indirect land use effects. Both narrow and comprehensive boundaries appear in existing protocols, reflecting different value propositions and answering different questions about the BiCRS credit's meaning and function. Accounting using narrow system boundaries can accelerate early deployment by focusing on incremental emissions reductions within the immediate control of a project developer, whereas accounting under comprehensive system boundaries provides a more accurate representation of total atmospheric impact and reduces the risk of locking BiCRS pathways into dependence on emissions-intensive upstream systems. But narrow boundaries should not be treated as a permanent substitute for comprehensive boundaries.

Expanding from narrow to comprehensive system boundaries to reflect net atmospheric carbon impact would not be equally straightforward across all BiCRS pathways. Pathways integrated into existing commodity markets, and large-scale vertically managed industrial supply chains, such as pulp and paper and corn ethanol, or traceable, commodity-like waste feedstocks for biofuels such as fats, oils, and greases (used cooking oil, tallow) are comparatively well positioned to adopt broader boundaries because upstream material and energy flows are already or could be tracked within existing accounting systems. In contrast, pathways that rely on highly diverse or distributed waste streams, including municipal solid waste, wastewater sludge, and animal manure, face substantially greater challenges because the system boundary extends across fragmented and poorly instrumented supply chains. Nonetheless, advances in digital traceability, remote sensing, and artificial intelligence–based monitoring and verification are rapidly reducing these barriers. While full lifecycle accounting will remain more difficult for some pathways than others, these challenges should be treated as implementation hurdles rather than justification for permanently narrower boundaries. Since the objective of BiCRS crediting is to reflect true atmospheric impact, system boundary expansion toward comprehensive accounting boundaries represents an important evolution in the BiCRS field. Further research should be undertaken to understand how boundary choices affect crediting outcomes across diverse BiCRS pathways.

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47 Byproducts of current activities.

Cross-cutting Recommendation 1: Adopt comprehensive boundaries in protocols that account for all significant sources of emissions in BiCRS systems with traceable supply chains, and work toward them in all other systems.

Protocols should establish comprehensive system boundaries, accounting for all major emissions across the entire BiCRS supply chain, including standardizing coproduct allocation, and including emissions associated with biomass feedstocks to the extent they can be reasonably attributed. Comprehensive system boundaries are achievable today and particularly important for BiCRS systems using feedstocks with commodity markets or large-scale industrial supply chains such as corn for ethanol, woody biomass from standing forests for power, and well-established and traceable commodity-like wastes for biofuels (such as tallow and used cooking oils). For BiCRS systems that use diverse and distributed waste sources, this may not currently be feasible to implement and warrants further research. This recommendation would ensure that credits reflect genuine net removals, reduce the lock-in of net-emitting processes in the future, and encourage the use of more sustainable biomass resources and higher-quality BiCRS systems.

Cross-cutting Challenge 2: Balancing flexibility with rigor

The BiCRS industry faces tension between the need for stable, rigorous, and credible standards, and the need for flexibility as science and technology evolve. Success depends on maintaining stability for project developers and investors, which is essential for securing financing, *and* on establishing rigorous standards to build market credibility and avoid the pitfalls seen in earlier carbon sectors, such as low-quality credits from inadequate forest carbon protocols. Investors seek stability to secure long-term financing, favoring longer crediting periods and clearly defined rules. Frequent or unpredictable protocol changes, though scientifically justified, create regulatory risks that can hinder project development.

At the same time, BiCRS protocols must remain scientifically adaptable, as the field continues to evolve rapidly in technology, measurement, and best practices.

Inflexible protocols may fail to incorporate rapidly advancing scientific knowledge and technologies, such as improvements in quantifying removals (e.g., through novel sensors or remote sensing), machine learning, or engineered sequestration methods. As a result, market participants may be compelled to use less accurate or more expensive methodologies simply because these are the only approved options, undermining both rigor and innovation.

Adaptive mechanisms that absorb new knowledge, improve greenhouse gas measurement precision, and stay aligned with advancing climate science can maintain rigor while allowing flexibility. Protocols can ensure this balance via strict outcomes, flexible approaches, and scheduled review mechanisms. This can include prioritizing verifiable, non-negotiable outcomes such as permanence and net removal (stringent), while allowing flexibility in the methods or technologies used to achieve them. Predetermined review periods for protocols (e.g., every five years) instead of ad hoc updates can enable transparent integration of scientific advances without destabilizing investor confidence. Stringent protocols establish the credibility essential for market sustainability, while built-in flexibility ensures they remain responsive, innovative, and capable of scaling globally.

Cross-cutting Recommendation 2: Embed adaptive mechanisms in protocol design to foster innovation but allow for improvements over time.

Protocols should use conservative defaults that are likely to underestimate rather than overestimate climate benefits, have regularly scheduled parameter updates, and allow developers to opt into voluntary upgrades to newer versions. Longer crediting periods with scheduled parameter reviews, enabling updates without disrupting projects, and allowing voluntary upgrades to newer protocol versions during a project or crediting period without penalty, can also promote innovation and continuous improvement, balancing flexibility with scientific rigor.

Cross-cutting Challenge 3: Improving consistency across protocols

Registries and protocols differ in how they address crucial features. Creating consistency across these key features could support unified market expectations and reduce confusion among buyers. Similar high-quality standards for accounting integrity should exist across all protocols related to features that are crucial to carbon accounting, including biomass sourcing and production emissions, avoided emissions, coproduct emissions allocation, durable storage monitoring, insurance or buffer pools, and overall system boundaries. This will require collaboration among actors in the BiCRS ecosystem, as different registries and protocols vary widely, and there is no clear authority to enforce alignment.

Cross-cutting Recommendation 3: Create consistency in the approaches to greenhouse gas accounting across protocols to ensure equivalent crediting outcomes.

Protocols should establish similar high-quality standards for the eight crucial features defined here and attention should be paid to the additional 10 features considered in this analysis. In particular, to work toward consistent system boundaries for greenhouse gas accounting, protocols should always disclose whether narrow, comprehensive, or another system boundary approach was used to estimate net carbon removal so that CDR buyers are informed.

Conclusion

Implementing our recommendations for strengthening and improving consistency in BiCRS protocols can enhance the climate integrity of BiCRS credits while enabling innovation in a rapidly evolving field. To scale BiCRS successfully, both technological advancements and robust standards are essential to demonstrate the effectiveness of these systems, inspire market confidence, and guarantee lasting environmental benefits. While the recommendations outlined here present implementation challenges of varying difficulty, these barriers are not insurmountable, and proactive planning to address them is essential to building a carbon removal industry that remains trusted, credible, and resilient over the long term. Our findings provide a roadmap for governments designing compliance markets, carbon credit registries, and others to strengthen protocol design and ensure that BiCRS systems both scale and deliver their intended climate benefits.

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APPENDIX

Appendix A

Data

Link to supplemental data file with full dataset, including detailed descriptions of approaches, assigned weights, and additional features of each protocol that were not subject to scoring: BiCRS Protocol Assessment Data For Report.xlsx

Methodology

We evaluated 25 BiCRS protocols using the versions that were available as of May 1, 2025. We note that several protocols have been updated since that time. Each protocol's approach to the 18 features was summarized, grouped by similarity, and organized by BiCRS system component. These approaches were coded and evaluated independently from their original protocol. Each expert scored the 94 coded approaches on a seven-point Likert scale: fundamentally flawed (represented numerically as 1), very weak, weak, satisfactory, robust, very robust, and exemplary (represented numerically as 7), using their judgment of an ideal approach, based on current science rather than comparing among protocols. Median scores are reported. Experts also assigned weights to the 18 features within each of the four components, and to the four components relative to one another, based on their importance for BiCRS carbon credit quality. Because feature importance may vary by BiCRS project types, experts provided weights for a generalized BiCRS project and for BECCS and biochar projects specifically. Experts were provided with default weights before scoring, so we normalized the weights; and here we report changes
in weights[48] to address potential bias. The percent changes in feature and component weights were then applied to the individual feature scores to recalculate the weighted aggregate score for each protocol. Experts met in person for two full days in June 2025 to discuss, clarify, and share information; afterward, participants could revise their initial scores and weights. All summarized approaches, scores, and applied weights are available in the supplemental data file.[49]

Experts were selected following Hemming et al. (2017).[50] We established relevant knowledge criteria for a transdisciplinary expert committee with expertise across BiCRS systems from biomass production, collection, and source, to bioconversion, carbon storage, economics, and system-level or lifecycle assessment models and created a list of potential participants including their specialization or skills and contact details. We mapped experts and related information in a database before conducting initial conversations with potential experts and selecting a final expert committee. We aimed for group diversity including career stage, gender and scope of geographic expertise and experience, and to ensure independence, anyone with an actual or perceived conflict of interest (including any financial stake in BiCRS companies) were excluded.

48 We did not test for a significant directional change.

49 When experts were from the same organization, their approach scores and feature and component weights were aggregated into a single expert score.

50 Hemming et al. (2017) A practical guide to structured expert elicitation using the IDEA protocol. Methods in Ecology and Evolution. https://doi.org/10.1111/2041-210X.12857

External Experts:

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- **Sarah Baker**, PhD, Group Leader, Materials for Energy and Climate Security; Associate Program Leader for Carbon Dioxide Conversion, *Lawrence Livermore National Laboratory (LLNL)*
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- **Angelo Gurgel**, PhD, Principal Research Scientist, *Massachusetts Institute of Technology (MIT)*
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- **Gal Hochman, PhD**, Professor of Environmental and Resource Economics in the Department of Agricultural and Consumer Economics, *University of Illinois Urbana-Champaign*
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- **Lisa Schulte Moore**, PhD, Charles F. Curtiss Distinguished Professor in Agricultural and Life Sciences, Professor, Natural Resource Ecology and Management, Director, Bioeconomy Institute, Director, C-CHANGE Grass2Gas, *Iowa State University*
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Figure 5. Protocol features, summarized approach, and approach scores by BiCRS system component.

More detailed descriptions of each approach are available in the supplemental data file.

Feature Name	Summarized Approach	Score
Component #1: Biomass Production, Collection, and Transport		
How is the alternative fate of biomass carbon in absence of the project determined and accounted for?	Regional/market-based analysis that biomass is regionally abundant and not used in existing markets.	Robust
	Explicit project-specific counterfactual analysis of biomass fate is required.	Satisfactory
	Excludes some emissions by applying a cut-off or carbon-neutral criteria in system boundaries.	Weak
	Assumes default baseline fate based on restriction to waste biomass only.	Weak
	Not discussed.	Fund. Flawed
Under what criteria are biomass feedstocks eligible?	Specific criteria based on sustainability, market leakage, and counterfactual storage filters.	Robust
	Approved feedstock lists and sustainability certifications.	Satisfactory
	Specific criteria based on technical characteristics, such as lignin content.	Weak
	Not discussed.	Fund. Flawed
What are requirements for verifying biomass meets eligibility criteria?	Requires chain-of-custody and digital tracking for full traceability of biomass origin, handling, and use.	Robust
	Requires basic tracking of biomass origin and type; no specific systems required.	Satisfactory
	Either a mass balance or a physical segregation system required across the value chain.	Satisfactory
	Nominally required, but no details on implementation.	Very Weak
	Not discussed.	Fund. Flawed
What are the requirements for demonstrating additionality?	Project-based regulatory, financial, and counterfactual criteria with regular reassessment.	Robust
	Performance-based criteria, such as approved feedstock lists. No financial assessment required.	Satisfactory
	Project-based regulatory and financial analysis, reassessment not required.	Weak
	Not discussed.	Fund. Flawed

Feature Name	Summarized Approach	Score
To what extent are emissions from biomass production, collection, and transportation included in removal quantification?	Full inclusion and explicit quantification for both purpose-grown and other (e.g., waste) biomass.	Very Robust
	Full inclusion only for purpose-grown biomass. May rely on default factors.	Satisfactory
	Optional, may be allocated to non-CDR coproducts.	Weak
	Excluded based on restricting eligible biomass to waste only.	Weak
	Nominally included, but no details specified.	Very Weak
	Not discussed.	Fund. Flawed
How are the sources of indirect leakage emissions determined and mitigated?	Specific types of leakage assessed; deduction required based on threshold.	Robust
	Comprehensive assessment and deduction of market, ecological, and activity leakage.	Satisfactory
	Excluded; assumed negligible based on restricting the eligible biomass to waste only.	Weak
	Not discussed.	Fund. Flawed
Component #2: Biomass Preprocessing and Bioconversion		
How is the baseline scenario for the BiCRS facility established?	Project-specific and scientifically justified based on modeling or carbon behavior assumptions.	Satisfactory
	Default baseline assuming no project, typically set at zero carbon removal.	Satisfactory
	Based on a comparison to conventional market practices.	Satisfactory
	Distinct approaches for new builds versus facilities retrofitted with CDR equipment.	Weak
	Not discussed or only implied.	Very Weak
How are emissions that are avoided due to displacement by the BiCRS system accounted?	Explicitly excluded.	Robust
	Included with justification using LCA, emission factors, or project substitution logic.	Weak
	Not discussed.	Very Weak

Feature Name	Summarized Approach	Score
To what extent are emissions from biomass preprocessing and bioconversion included in removal quantification?	Full inclusion of all relevant sources in quantification.	Very Robust
	Included under conditions; new builds, non-renewable energy sources, or specified GHGs only.	Weak
	Included using conservative default values or emissions factors.	Weak
	Excluded based on a narrow system boundary limited to capture and storage.	Very Weak
	Not discussed.	Fund. Flawed
How are emissions from the BiCRS system allocated among CDR and coproducts?	Full allocation of emissions to the CDR process regardless of coproducts.	Satisfactory
	Based on standardized principles, such as energy or mass balance.	Satisfactory
	At project discretion (partial, full, none), often requiring justification.	Weak
	Depends on context such as value of coproduct, requirements specified.	Weak
	Not discussed.	Fund. Flawed
Component #3: Capture and Storage		
To what extent are emissions from carbon capture and storage included in removal quantification?	Full inclusion of all relevant sources in quantification.	Very Robust
	Operational and process emissions included; allocated proportionally if shared with other processes.	Satisfactory
	Partial inclusion; may exclude certain GHGs or post-capture transport emissions as negligible.	Weak
	Not discussed.	Fund. Flawed
How long is the durable storage of carbon monitored?	Context-dependent, based on process, location, and/or risk profile; emphasize adaptive approaches.	Satisfactory
	Minimum duration is specified, usually based on regulatory or technical benchmarks.	Satisfactory
	No monitoring duration specified, but monitoring data is required beyond the crediting period.	Weak
	No monitoring duration specified.	Fund. Flawed

Feature Name	Summarized Approach	Score
How is risk of carbon rerelease evaluated and mitigated?	Site-specific risk evaluations and monitoring, buffer pools, and regulatory controls.	Very Robust
	Prescribed risk assessments based on storage type.	Satisfactory
	Prescribed risk assessment based on material type.	Weak
	Includes potential re-release from storage as part of lifecycle emissions.	Weak
	No formal risk assessment or mitigation plan; based on the assumption of negligible risk.	Very Weak
What is the approach to measuring, monitoring, reporting, and verifying (MMRV) the project?	Direct monitoring, including leak detection and explicit response mechanisms.	Robust
	Regular monitoring, performance indicators, may not focus on real-time leak detection.	Robust
	Relies on relevant existing jurisdictional regulations rather than internal details in protocol.	Satisfactory
	Little or no monitoring required.	Fund. Flawed
How is the stored carbon insured against potential rerelease?	Default buffer pool contribution of 0-6% based on relevant storage, range includes all types.	Satisfactory
	Default buffer pool contribution of 5% for CO2 in geological formations.	Satisfactory
	Default buffer pool contribution of 2.5-3% for CO2 or organic carbon in geological formations.	Satisfactory
	Project-specific buffer pool contribution of 0-15% based on risk for organic carbon in construction materials.	Satisfactory
	A 10% default buffer pool contribution for biomass burial that may be reduced after 5 years. Alternate insurance permitted.	Satisfactory
	A binding 100-year contractual framework against reversal, with multiple acceptable mechanisms.	Satisfactory
	Project-specific buffer pool contribution without a specified range (applies to biomass burial).	Satisfactory
	Deducts up to 25% as a default stability factor (applies to marine burial).	Satisfactory
	Not specified (applies to CO2 in concrete).	Weak
	Relies on existing relevant jurisdictional regulations rather than on details in the protocol.	Weak
	Not specified (applies to biochar).	Very Weak
	Not specified (applies to organic carbon in construction materials).	Fund. Flawed

Feature Name	Summarized Approach	Score
Component #4: Overall System		
How are embodied emissions from equipment and other inputs considered?	Included for all equipment and allocated over a specified timeline; quantified at the project level.	Very Robust
	Included for purpose-built equipment for CDR; quantified at the project level.	Robust
	Included for purpose-built equipment for CDR; may rely on emissions factors.	Satisfactory
	Excluded; assumes facilities are already operational.	Weak
	Included as part of a required LCA, but no details provided.	Weak
	Not discussed.	Fund. Flawed
How long can project earn credits under approved design (crediting period) and when are credits issued?	Renewed every 5 years; credits are only issued after independent verification.	Satisfactory
	Renewed every 5 years; provisional credits may be sold before, but only transferred after independent verification.	Satisfactory
	Renewed every 6-10 years; credits are only issued after independent verification.	Satisfactory
	Renewed every 15 years; credits are only issued after independent verification.	Weak
	Length not clearly stated; credits are only issued after independent verification.	Very Weak
	Length not clearly stated; credits are only issued after verification by storage site operator.	Very Weak
How is uncertainty in carbon removal calculation handled?	All sources are reported with sensitivity analysis. Variables with <1% effect on removals are excluded; all others are incorporated into removal quantification.	Very Robust
	All sources are calculated and reported. Discount applied for total uncertainty >10%, starting at 2.5% and scaling upward.	Satisfactory
	All sources with >1% effect on removals must be reported. No deduction specified.	Satisfactory
	Categorical (low, medium, high) uncertainty estimated based on all sources. Discount factor of 3%, 6%, or 9+% applied by category.	Satisfactory
	Deduction of 0.1% to 1% of removals, based on project-specific or default values.	Weak
	Sources related only to physical leakage monitoring reported. No deduction specified.	Very Weak
	Not discussed.	Fund. Flawed