(carbon)plan

OCT 6, 2025

Carbon Capture, Removal, Utilization, and Storage Program
California Air Resources Board
1001 I Street
Sacramento, CA 95814

RE: Information Solicitation to Inform Implementation of SB 905

To Whom It May Concern:

Thank you for the opportunity to provide comments to inform the implementation of SB 905.[1]

For context, CarbonPlan is a nonprofit research organization dedicated to the integrity and transparency of climate solutions. Our carbon dioxide removal (CDR) program focuses on researching emerging approaches to CDR and synthesizing the best available science for decision-makers.[2] We also have extensive experience evaluating CDR projects and protocols.[3]

Below, we respond to questions 3, 4, and 22 - 26.

Question 03. Are there any project categories missing from this list?

Yes. If CARB is seeking a set of categories that reflects the wide variety of carbon dioxide removal (CDR) approaches being explored today, the list should be expanded.

Several notable categories are missing.

- *Alkalinity-based sequestration*: This includes adding alkaline materials to agricultural soils, rivers, or wastewater treatment facilities to increase water's capacity to hold carbon without acidifying. It also could include approaches to weathering alkaline waste materials in a manner that captures carbon through mineralization. These approaches to CDR are the focus of growing academic research and, despite scientific uncertainties, projects in this category are beginning to appear in voluntary carbon markets.[4]

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1 California Air Resources Board, Information Solicitation to Advise Implementation of the Carbon Capture, Removal, Utilization, and Storage Program: Senate Bill 905 (2025).

2 See, *e.g.*, CarbonPlan and Frontier, CDR Verification Framework, CarbonPlan (2023); Tyler Kukla et al., Does Enhanced Weathering Work? We're still learning., CarbonPlan (2024); CarbonPlan and [C]Worthy, Mapping Marine CDR, CarbonPlan (2025).

3 See, *e.g.,* Freya Chay et al., CDR database, CarbonPlan (2021); Jane Zelikova et al., A buyer's guide to soil carbon offsets, CarbonPlan (2021); Grayson Badgley et al., Systematic over-crediting in California's forest carbon offsets program, *Global Change Biology (2021)*.

4 *See* Jesper Surhoff, Bibliography of Enhanced Weathering Literature, Zenodo (2025) for a comprehensive, living list of publications about alkalinity-based sequestration approaches. Protocols for crediting this project category in the voluntary carbon market include: Enhanced Rock Weathering in Agricultural Fields

- *Ocean chemistry-based sequestration*: This includes removing carbon directly from surface waters to drive ocean re-uptake (often called direct ocean capture or direct ocean removal), as well as ocean alkalinity enhancement. Both approaches are the focus of growing academic research and, despite scientific uncertainties, are beginning to appear in voluntary carbon markets.[5]
- *Ocean biology-based sequestration*: This includes approaches that manipulate marine ecosystems or biological processes to increase carbon storage. These remain earlier-stage, with more scientific uncertainty and little commercial activity to date.[6]

Question 04. Are there suggestions for further description of these categories, or ways to group categories?

Yes. It would be helpful to group CDR categories along two key attributes: (1) the durability of carbon storage realistically expected from a project category, and (2) the level of uncertainty associated with quantification.

While all CDR activities remove CO2 from the atmosphere, they differ widely in how they alter the carbon cycle, the maturity of their development, and the level of uncertainty around quantifying their impacts. This diversity means that not every category of CDR needs the same type of support from CARB's Carbon Capture, Removal, Utilization, and Storage Program — nor is every category of CDR a good fit for every policy mechanism. Compliance offset policies, for example, aim to ensure that removals neutralize a given quantity of emissions. They should therefore only rely on CDR categories that have millennial timescale durability and high quantification certainty, as we discuss further below. Other policy mechanisms, like "pay for practice" subsidies or research and development (R&D) programs, can support a wider set of activities, helping expand the portfolio of options that can contribute to the state's long-term climate goals.

Durability

CARB should differentiate CDR project categories based on durability in order to align CDR projects with the appropriate type of policy support. CARB should ensure that shorter-lived forms of CDR are valued, but not asked to play a role in California policy (i.e., compensating for fossil CO_2 emissions on a ton-for-ton basis) that they cannot realistically achieve.

The durability of carbon storage achieved by a CDR project fundamentally determines the role it can play in helping California reach and sustain its 2045 carbon neutrality goal.[7] From a physical climate perspective, the warming caused by CO_2 emissions can only be counteracted by removing carbon from the atmosphere and storing it on timescales

(v1.1), and Open System Ex-situ Mineralization (v1.0), Wastewater Alkalinity Enhancement (v1.1), and River Alkalinity Enhancement (v1.0) from Isometric, and the Enhanced Rock Weathering Methodology (v0.9) from Puro.

5 *See* Andreas Oschlies et al., Perspectives and challenges of marine carbon dioxide removal, *Frontiers Climate* (2025). Protocols for crediting this project category in the voluntary carbon market include: Ocean Alkalinity Enhancement from Coastal Outfalls (v1.0) and Direct Ocean Capture and Storage (v1.0) from Isometric.

6 *See* Andreas Oschlies et al., *supra* note 5. As far as we are aware, there are not currently protocols for crediting this project category in the voluntary carbon market.

7 CA Health & Safety Code § 39740.

commensurate with the atmospheric lifetime of CO_2. In practice, this means that to achieve true carbon neutrality and long-term temperature stabilization, any fossil CO_2 emissions must be balanced by CDR that delivers essentially permanent storage.[8]

California has not yet adopted this scientifically grounded standard of permanence. Instead, both statute and CARB regulations currently rely on a 100-year storage requirement.[9] Under either benchmark — the physically robust definition of permanence or CARB's 100-year standard — it is important to differentiate categories of CDR based on the durability of carbon storage they can realistically achieve.

Nature-based solutions, such as enhancing carbon storage in forests and soils, are valuable but inherently reversible. Their durability is shaped by both human decision-making (e.g., harvesting, tillage) and physical risks that are difficult to control (e.g., wildfire, pests, disease).[10] These approaches cannot satisfy the physical robust definition of permanence. Even meeting the 100-year threshold requires robust and trustworthy human institutions to monitor and insure against reversals, a task that has already proved difficult in the context of California's compliance offset program.[11]

In contrast, many emerging CDR pathways offer storage far longer than 100 years. Usually, this expectation of durability is based on physical processes that, according to the best available scientific understanding, are less susceptible to reversal. For example, the residence time of extra dissolved inorganic carbon stored in the ocean is expected to lie somewhere between 10,000 and 100,000 years. Similarly, if injected CO2 mineralizes, the resulting rocks are expected to store carbon on geologic timescales.

In between these two extremes are a variety of pathways (e.g. biochar or biomass burial) whose durability depends directly on project-specific implementation choices.

Treating all of these pathways the same way ignores the reality that they are suited to very different roles in the climate mitigation toolkit. All may merit policy support, but are not all suited for incorporation into compliance programs.

Quantification uncertainty

Differentiating CDR categories by uncertainty is equally important for determining appropriate policy integration and support. CARB should develop a typology of uncertainty to characterize CDR categories, and use this typology to inform decisions about the types of policy mechanisms that are appropriate for funding a given CDR activity.[12]

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[8] Sam Frankhauser et al., The meaning of net zero and how to get it right, *Nature Climate Change* (2021); Myles Allen et al., Net Zero: Science, Origins, and Implications, *Annual Review of Environment and Resources* (2022); Myles Allen et al., Geological Net Zero and the need for disaggregated accounting for carbon sinks, *Nature* (2024).

[9] California Code of Regulations, Title 17, § 95802 (defining "permanent" as "endur[ing] for at least 100 years.").

[10] *See, e.g.*, Jazlynn Hall et al., Forest carbon storage in the western United States: Distribution, drivers, and trends, Earth's Future (2024); William R. Anderegg et al., Future climate risks from stress, insects and fire across US forests, *Ecology Letters* (2022).

[11] Grayson Badgley et al., California's forest carbon offsets buffer pool is severely undercapitalized, *Frontiers in Forests and Global Change* (2022).

[12] We do not propose a typology here; CARB's should be guided by its program implementation priorities. One potential source of inspiration is the CDR Verification Framework, which our team developed with Frontier, a leading CDR buyer. The framework catalogs the factors that contribute to quantification uncertainty across

All CDR pathways face quantification challenges, but they differ widely in terms of how confidently we can observe removal, establish counterfactuals, and quantify atmospheric outcomes.

For example, we have relatively high confidence in the gross carbon removal achieved by direct air capture projects. We can directly observe how much CO_2 is captured by a plant and injected into a storage reservoir. Similarly, approaches to monitoring the integrity of carbon storage in geologic reservoirs is fairly well developed. The primary challenge for quantifying the net impact of a DAC project on the atmosphere is one of accounting — specifically, accounting for the carbon impact of DAC's significant energy use.[13]

In contrast, quantifying the impact of enhanced rock weathering is an active area of research.[14] Although it's easy to quantify how much rock dust is put on fields, it's harder to directly observe when that rock dust weathers. Tracing the effects of weathering through space and time, and ultimately to carbon storage in the ocean, relies on models. Progress on these scientific questions and the associated quantification tools is critical for understanding where and when ERW can be an effective form of CDR.

Biomass carbon removal and storage (BiCRS) approaches, including BECCS, present two additional types of uncertainty: counterfactual uncertainty and system uncertainty. Most BiCRS projects do not cultivate their own biomass but instead rely on waste or residual feedstocks, such as forest thinnings. It is often assumed that storing this biogenic carbon automatically benefits the atmosphere, but this is only true if the carbon stored by the project would otherwise have been emitted — a counterfactual that can carry significant uncertainty. Larger-diameter biomass in dry environments, for example, can take decades to decay if left in place rather than used in a BiCRS project.[15]

Assessing the role of BiCRS within California's broader climate strategy additionally requires a system perspective — one that accounts for the carbon dynamics of the sink from which biomass feedstocks are sourced. As a hypothetical example, imagine BiCRS projects that rely exclusively on forest thinnings from California forests expected to lose carbon over the next 50 years.[16] In this case, storing thinnings would slow the rate of forest carbon loss, effectively shifting carbon previously stored in natural and working lands into a more stable reservoir. However, such projects could not, from a system perspective, compensate for the state's industrial emissions. This example illustrates that understanding BiCRS impacts requires tracing both the provenance of biomass feedstocks and the associated dynamics of the upstream carbon sink.[17] These factors can be difficult to

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CDR pathways and summarizes overall uncertainty in a single metric, the Verification Confidence Level (VCL). Frontier used the VCL to determine which pathways were eligible for offtake agreements.

[13] This carbon accounting challenge is not unique to CDR. There is an ongoing debate about the best long-run approach to clean energy procurement and accounting for sectors like clean hydrogen. *See, e.g.,* Wilson Ricks et. al., Minimizing emissions from grid-based hydrogen production in the United States, *Environmental Research Letters* (2023).

[14] *See* Jesper Surhoff (2025), *supra* note 4.

[15] Kevin Fingerman et al., Climate and air pollution impacts of generating biopower from forest management residues in California, *Environmental Research Letters* (2023).

[16] Scientific evidence suggests that western US forests, including in California, will lose significant amounts of carbon as they respond to the changing climate —- including more frequent and severe wildfires and droughts. *See, e.g.,* Hall et al. (2024), *supra* note 10.

[17] *See, e.g.,* Bodie Cabiyo et al., Impacts of unprecedented wood demand for bioenergy in the Southeastern

monitor and may introduce substantial system uncertainty into BiCRS project accounting.

In sum, quantification uncertainty must be considered explicitly for CARB to evaluate the efficacy and viability of CDR technologies and facilitate real-world project implementation in a way that supports the state's climate goals.

Question 22. What role could projects developed under SB 905 play in these programs and are there other programs or policies in which carbon capture removal, storage, and utilization could play a role for compliance?

CARB should only consider projects that deliver permanent carbon storage with a high degree of confidence for inclusion in compliance programs, like California's cap-and-trade programsee Question 04). Temporary removals or approaches with significant quantification uncertainty are not appropriate for this role. However, temporary carbon storage projects can still be supported through other policy mechanisms that recognize their contributions to the state's carbon balance without justifying ongoing fossil emissions.

Question 23. Are there other things the state could be doing to scale up deployment of projects under SB 905?

Yes. A primary rationale for investing in CDR today is *learning*. Learning can occur across multiple dimensions:

- *Scientific*: Under what conditions does the approach remove CO_2 from the atmosphere?
- *Practical*: Can the approach be implemented at scale in the real world?
- *Political and social*: Are communities and policymakers willing to accept any trade-offs associated with the approach? Is its implementation compatible with a broader transition away from fossil fuels?

It is important to maintain a clear standard for the level of knowledge that is necessary for using a CDR project as a compliance offset. At the same time, policy has an important role in developing less certain approaches by facilitating R&D funding and making learning an explicit goal of early-stage deployments for less-certain pathways.

Question 24. Is there a potential role for carbon removal using climate-smart agriculture practices under the SB 905 framework?

Carbon removal through climate-smart agriculture practices could have a role under the SB 905 framework, but not for compliance uses that reduce emissions-reduction requirements.

Soil carbon projects are highly uncertain, difficult to quantify, and reversible, making them unsuitable for compliance-grade credits.[18] It is more straightforward and defensible to

US (preprint, 2025), which shows that even intuitive rules — like requiring that the forest from which biomass feedstocks are sourced must be stable or growing — might fail to ensure additional carbon removal on the system level compared to the baseline.

[18] *See, e.g.,* Gabriel Popkin, Shaky Ground, *Science* (2023), which details concerns from the scientific community around using existing models to quantify soil carbon changes and issue offsets.

value these approaches for their co-benefits, such as soil health, water retention, and ecosystem services. Enhanced rock weathering (ERW) could contribute to agricultural pH management, but it also faces quantification challenges and high uncertainty. Both approaches are more appropriate for research, pilot projects, or incentive programs that recognize their potential benefits without substituting for emissions reductions.

Question 25. Are there certain carbon capture, removal, utilization, and storage project type methodologies that should be prioritized based on existing science, existing methodologies, or implementation experience?

The answer depends on the sense of "prioritization" that CARB has in mind. If the purpose is to generate compliance-grade credits that offset ongoing emissions, then methodologies should be limited to project types that offer highly durable carbon storage with relatively low quantification uncertainty (see Question 04).

If the purpose is broader — supporting learning, advancing development, and enabling approaches with significant long-term potential — then a wider range of projects should be prioritized. Less understood but potentially more scalable approaches, such as enhanced rock weathering, may warrant near-term focus even if they are not currently appropriate for compliance markets. Such focus could encourage the development of a broad portfolio of CDR to support the state's future climate goals.

In short, prioritization should distinguish between (1) methodologies suited for compliance and (2) methodologies to support for research, development, and demonstration. Both pathways are essential, but they require different standards and policy mechanisms.

Question 26. Should CARB consider adopting project type specific protocols or defining more widely applicable standards, or a combination of both? If CARB were to define key standards applicable to all methodologies as opposed to individual methodologies based on specific technology or storage, what could those look like (i.e. recommendations on existing standards), and would that approach help to scale and innovate in this space faster than development of individual protocols?

CARB should consider a combination of approaches.

First, CARB should focus on establishing a widely applicable standard defining what must be true for a carbon removal project to participate in compliance programs. CARB should prioritize holding a high bar around additionality, durability, and quantification certainty (see Question 04).

CARB could also consider developing standards for elements like geologic storage or energy accounting that are shared across CDR and CCS projects and are relatively well understood. These standards could serve as an authoritative and rigorous bar that private and public entities involved in pathway-specific protocol development could adopt.

CARB should avoid developing detailed standards for CDR categories that are still evolving rapidly, unless it's ready to dedicate significant capacity to developing and frequently updating protocols. CARB standards are viewed as authoritative, and codifying such standards prematurely may actually be counterproductive by creating a stamp of approval on quantification and accounting approaches that may quickly become out-dated as science develops.

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Sincerely,

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