



Exploring Biomass Carbon Removal and Storage (BiCRS) Scenarios for California

Summary for Policymakers

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CLEAN AIR
TASK FORCE



Executive Summary

California faces several interrelated challenges: how to remove carbon pollution from the atmosphere, protect communities from wildfires, keep working lands working, and grow the clean energy economy. One promising solution is to extract the carbon from wastes and residues, like forest thinnings and crop leftovers, and store it deep underground. This approach, called Biomass Carbon Removal and Storage (BiCRS), could help the state reach its climate goals faster and more affordably, while improving public health, creating jobs, and strengthening rural economies.

BiCRS systems offer a significant opportunity for scaling carbon dioxide removal (CDR) in states such as California that have a large supply of biomass wastes and residues. In addition to mitigating climate change, BiCRS systems can provide a low-carbon energy source, help address air quality concerns associated with biomass burning and wildfires, return nutrients to soil via biochar coproducts, reduce synthetic fertilizer demands and related water quality issues, and provide markets to farmers for residue management.¹

This report explores seven scenarios for integrating BiCRS into the state of California's CDR targets, with a focus on the utilization of wastes and residues. Currently, California's 2022 Scoping Plan for achieving its CDR target relies largely on direct air capture (DAC). Specifically, DAC accounts for 64 million metric tonnes (MMT) of carbon dioxide equivalent (CO₂e) of the 75 MMT target in 2045. Bioenergy with carbon capture and storage (BECCS) systems that produce hydrogen are estimated to provide another 9 MMT annually. Due to the rapid advancement of CDR research in recent years, including Lawrence Livermore National Laboratory's (LLNL) 2023 report, *Roads to Removal*, the potential exists to integrate a wider array of CDR solutions, such as BiCRS, into future planning efforts. Given the large volume of biomass wastes and residues in the state and the need to manage forests to reduce wildfire severity, protect life-safety, and increase resilience to future climate change, the portfolio of CDR solutions in the Scoping Plan could be expanded to include multiple BiCRS systems to meet the target and confer additional benefits to the ecosystems, people, and economy of California.

¹ "California's largest contribution to removing CO₂ can be from municipal trash, plus forest and agricultural wastes. Keeping this carbon from returning to the air solves two problems: less landfill and water runoff contamination, and less smoke pollution from fires." "BiCRS in the Central Valley [in California] can remove large amounts of agricultural residue that would otherwise be burned, removing a major area health hazard." https://roads2removal.org/wp-content/uploads/California_RtR_Factsheet_v-06_FINAL_2_27_24_V3.pdf

We used stakeholder surveys and interviews to understand the barriers and enablers to BiCRS deployment and to design illustrative BiCRS scenarios in California. The modeled scenarios represent different portfolios of BiCRS technologies that could be deployed to meet the state's diverse goals. The purpose of the scenarios is to compare the pros and cons of several divergent BiCRS technology pathways to inform future planning, not to produce a preferred normative scenario. Based on stakeholder input, we constructed a scenario matrix using drivers of social acceptance and costs for specific BiCRS systems (see Section 2.2 for more information on these metrics). We then modelled how BiCRS systems may be deployed under those constraints.

The four resulting primary scenarios are:

- Scenario 1: Higher Cost, Lower Social Acceptance
- Scenario 2: Higher Cost, Higher Social Acceptance
- Scenario 3: Lower Cost, Lower Social Acceptance
- Scenario 4: Lower Cost, Higher Social Acceptance

We used biomass availability estimates from the *Roads to Removal* report for these four primary scenarios. We modeled three additional scenarios that used a lower estimate of mobilizable forest residues from the California Air Resources Board,² as well as a scenario focused on dedicating biomass to meet the state's sustainable aviation fuel (SAF) targets.

The three additional scenarios are:

- Scenario 2.1: Higher Cost, Higher Social Acceptance, with limited forest biomass
- Scenario 4.1: Lower Cost, Higher Social Acceptance, with limited forest biomass
- Scenario 4.2: Lower Cost, Higher Social Acceptance, with limited forest biomass and a SAF target

For each of the seven scenarios, we then estimated the tons of carbon removal achieved in 2045, the cost per ton of CDR, the amount of bioenergy produced, the number of jobs generated, and the total cost of the scenario.

Relative metric of social acceptance

We combined three data sets to develop a relative metric of social acceptance for BiCRS pathways used in this scenario analysis. See Appendix C for more details on how the metric was calculated.

Higher social acceptance pathways tend to use agricultural and forestry residues, minimize visible land use impacts, and include benefits like waste management, wildfire risk reduction, and rural job creation. These systems may require newer or emerging technologies, such as gasification or pyrolysis, that are not yet widely deployed at scale.

Lower social acceptance pathways generally rely on more established technologies—like biomass combustion—but may face pushback due to concerns about air pollution, industrial siting, or community impacts.

² California Air Resources Board (CARB) 2022 Scoping Plan. (2022) Appendix I – Natural and Working Lands Technical Support Document (pages 103-117). <https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp-appendix-i-nwl-modeling.pdf>

Comparing the results across the seven BiCRS scenarios for reaching California's 2045 CDR target, we found that:

1. All the scenarios are within the estimated cost range of the 2022 Scoping Plan, and some scenarios (Scenarios 4.1 and 4.2) are below it.
2. The significant volume of existing and projected waste biomass in the state means that substantial deployment of BiCRS can be achieved in California without competing with food production or inducing land use change.
3. Under high estimates of biomass availability, it would be feasible to meet the 2022 Scoping Plan CDR target (75 MMT CO₂e) solely with BiCRS (Scenarios 3 and 4).
4. Across all the scenarios and assumptions, BiCRS can supply a large amount of CDR, ranging from 13 to 75 MMT CO₂e.
5. Scenarios that deploy lower-cost BiCRS pathways show a prevalence of commercially available systems such as sawmills producing wood products and combustion to electricity with carbon capture and storage (CCS), as well as gasification to hydrogen with CCS.
6. Scenarios that deploy higher social acceptance BiCRS pathways tend to utilize crop and forest residues.
7. Higher social acceptance scenarios tend to deploy advanced bioconversion pathways that are not yet widely available at scale, including fermentation of lignocellulosic materials (such as forestry waste), gasification, pyrolysis to hydrogen, and sawmills to wood products.
8. In contrast, lower social acceptance scenarios tend to deploy more conventional bioconversion pathways that are currently in operation at scale, such as anaerobic digestion to biogas and biomethane with CCS, and combustion to electricity with CCS. Note, CCS is not currently deployed widely on these bioconversion systems.
9. All the BiCRS scenarios produce more bioenergy and jobs than estimated in the DAC focused 2022 Scoping Plan, with the higher social acceptance scenarios (Scenarios 2 and 4) resulting in the highest estimated bioenergy and job production, with about 10 times more than estimated for the 2022 Scoping Plan.
10. The estimated job and energy production outcomes vary widely, depending on the type of BiCRS deployed.

The results from the BiCRS modeling and analysis suggest that if the goal is to prioritize BiCRS pathways that are more likely to be widely socially accepted, then research, development, and deployment of advanced technologies will likely be necessary. Markets and incentives would be needed to support the deployment of high-cost pathways, and safeguarding policies could help ensure socially accepted and beneficial systems are deployed.

We suggest that efforts to build upon this report should include refining metrics of social acceptance and improving estimates of costs and jobs for BiCRS systems. Additionally, this study used two different estimates for forest-derived biomass in California: reconciling regionally specific biomass availability estimates from forests is needed to support CDR deployment and sustainable biomass utilization in the state.

This report presents an initial assessment of intentionally divergent illustrative BiCRS scenarios defined by metrics of cost and relative social acceptance in California, with a focus on waste biomass. The results highlight the opportunity to diversify the portfolio of CDR pathways for achieving the state's 2045 CDR target with BiCRS. The results suggest that a large fraction of the target could be achieved with BiCRS systems that rely on the utilization of waste feedstocks. Integrating BiCRS systems into the Scoping Plan could also reduce the estimated cost of achieving the target while providing additional jobs and bioenergy, while improving the resilience of forest and agricultural lands to climate change.

Policy considerations and recommendations

As California works to meet its ambitious CDR target, BiCRS offers an opportunity to deliver durable carbon removal alongside numerous co-benefits. These scenario results highlight the need for policy action to support alignment and build consensus around the most beneficial BiCRS target and pathways for California, including the following recommendations:

- Consider expanding and diversifying the portfolio of biomass-based CDR pathways in the next Scoping Plan update to include options beyond hydrogen-based BECCS. The scenario results demonstrate that there can be substantial benefits to carbon sequestration and non-fossil energy production from integrating broader BiCRS pathways. Many BiCRS pathways produce bioproducts like heat, electricity, fuels, and durable wood products that can be used to enable sector-specific decarbonization, like transportation, buildings, and industry. A diversified portfolio should balance the state's climate, air quality, public health, energy system, economic development, and land stewardship goals.
- Establish accounting standards for waste biomass carbon removal pathways, including BiCRS, that would ensure high-quality offsets for the purpose of achieving the 75 MMT CO₂e CDR target, with a clear distinction between different types and qualities of carbon offsets to prevent market distortion and promote higher-impact CDR.
- Advance state and regionally aligned estimates of available forest and agricultural waste biomass that incorporate both the technical availability and stakeholder consensus on BiCRS opportunities that align with local land management goals, community priorities, and broader state climate, air quality, and economic development objectives.³ As part of this process, conduct stakeholder engagement to gather regional perspectives on various BiCRS pathways. This can generate more robust data on social acceptance than currently exists, and surface utilization strategies are responsive to local context, values, and constraints.
- Implement SB 905 to establish a regulatory foundation for carbon removal and capture in California. Effective implementation of SB 905 will be essential to enabling the infrastructure and permitting frameworks needed for BiCRS projects, particularly those involving geologic storage. Key provisions include establishing safety and environmental standards for projects, creating a unitization framework for pore space, developing a unified permit application process, and identifying suitable storage locations for Class VI injection wells.
- Explore policies for government procurement of carbon removals using BiCRS pathways. Depending on how they are structured, government procurement at the state or federal level can support early projects and drive innovation in research, development of new CDR technologies, and/or they can support the scale-up in deployment of existing CDR systems with high technological readiness.⁴ While procurement in the traditional sense constitutes governments purchasing an already scaled product, procurement programs (sometimes categorized as prizes or R&D funding) can also bolster technology development and accelerate the innovation process to reach the final product. The purpose and intent of any procurement program should be clearly articulated from the start. Government procurement policies can also help support the nascent market for CDR and can encourage the early market growth needed for a BiCRS industry to reach a point where demand allows the market to be self-sustaining.

³ CATF developed a model for regional engagement and planning around clean energy futures through facilitated local/regional/state conversations in the San Joaquin Valley. This effort was supported by data on energy resource potential, including waste biomass. The report included a number of recommendations for combined state and local action and partnership. For more information, see ["An Exploration of Options and Opportunities for the San Joaquin Valley's Clean Energy Future."](#)

⁴ See more information on government procurement and additional policy options to scale carbon dioxide removals in the U.S. in CATF's 2025 report, [A Policy Framework for Scaling Up Permanent Carbon Dioxide Removal in the United States](#).

While developing a normative scenario based on the findings was out of scope for this report, our results suggest that if policymakers desire to prioritize BiCRS pathways that are more likely to be widely socially accepted and have the potential to produce more bioenergy and jobs, then supportive policy interventions at both the state and federal level will likely be needed to help develop markets for these emerging pathways. These pathways include the fermentation of lignocellulosic materials (such as forestry waste), gasification, pyrolysis to hydrogen, and sawmills producing wood products from forest biomass. To support these, the state could expand grant programs to help fund the production of fuels and durable wood products from waste biomass⁵; ensure that innovative wood products are integrated into CARB's embodied carbon framework and strategy⁶; and continue efforts to develop design-based pathways in the Low Carbon Fuel Standard for fuels derived from forest and agricultural waste. Additional efforts could include ensuring long-term feedstock supply contracts are available in the state to support access to financing, and providing additional pilot and demonstration funding to support small-scale, regional projects that are needed to break the "chicken and egg" problem in BiCRS infrastructure development where the development of the industry is hampered by both a lack of biomass supply chains and bioconversion facilities that would provide demand for biomass supply and actors on both sides are hesitant to invest without a guarantee of the other. Resolving this dilemma will require support and partnerships.

This report presents an initial assessment of intentionally divergent illustrative BiCRS scenarios defined by metrics of cost and relative social acceptance in California, with a focus on waste biomass resources available under sustainability constraints. The results highlight the opportunity to diversify the portfolio of CDR pathways for achieving the state's 2045 CDR target with BiCRS. The results suggest that a large fraction of the target could be achieved with BiCRS systems that rely on the utilization of waste feedstocks. Integrating BiCRS systems into the Scoping Plan could also reduce the estimated cost of achieving the target while providing additional jobs and bioenergy, and improving the resilience of forest and agricultural lands to climate change.

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⁵ The Department of Conservation's [Forest Biomass to Carbon-Negative Biofuels Pilot Program](#) is one such example of a program intended to demonstrate viable fuel pathways.

⁶ Assembly Bill(s) 2446 and 43 (Holden) require CARB to develop a framework for measuring and then reducing the average carbon intensity of the materials used in the construction of new buildings. <https://ww2.arb.ca.gov/our-work/programs/embodiedcarbon/about>