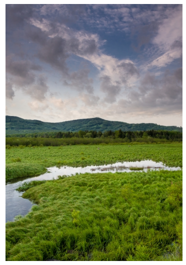

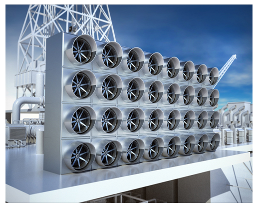

West Virginia University
BRIDGE INITIATIVE FOR S&T POLICY, LEADERSHIP, & COMMUNICATIONS

Carbon Dioxide Removal and West Virginia: A Science and Technology Policy Perspective

Pre-Publication Version

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This policymaker's guide is a product of West Virginia University's Bridge Initiative for Science and Technology Policy, Leadership, and Communications. The Bridge Initiative identifies challenges and opportunities facing West Virginia and provides a bridge between the science and technology expertise of WVU faculty and staff and West Virginia's national, state, and local policymakers. In our work, we gather the views of stakeholders throughout the state to ensure we are making recommendations that serve the needs of West Virginians. This work supports WVU's critical land-grant mission to lead "transformation in West Virginia and the world through local, state and global engagement."

To read the full policymaker's guide, please visit: http://scitechpolicy.wvu.edu

[Text to be added above between the two paragraphs.]

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Overview of West Virginia University Bridge Initiative

Carbon Dioxide Removal and West Virginia:

A Science and Technology Policy Perspective

C A	**Create Carbon Reduction Opportunities in West Virginia:** West Virginia has the most scientific and technological carbon reduction potential for CDR options using natural methods as well as bioenergy with carbon capture and sequestration (BECCS) and direct air capture (DAC). Whatever CDR options are chosen, care should be taken to establish appropriate standards and verification processes.	● Work with Federal agencies and leading nongovernmental organizations to develop appropriate standards for net carbon accounting of sequestered carbon. ● Fund a study by the National Academies of Science, Engineering, & Medicine on the appropriate criteria to consider in determining the optimal harvest cycle for maximizing the carbon removal potential by forests and forest products.
R	**Restore Carbon Into West Virginia's Natural Resources:** The chief challenge for the implementation of BECCS and DAC options is developing a better understanding of the ability to store CO_2 in West Virginia.	● Incorporate BECCS into the existing U.S. Renewable Fuel Standard. ● Fund a study that examines both community and technical opportunities and challenges to identify suitable locations for DAC demonstration projects in West Virginia.
B	**Benefit West Virginia's Economic Prosperity and Create Jobs for West Virginians:** CDR has the potential to generate economic prosperity and job creation, particularly in West Virginia's coal communities and other rural communities.	● Invest in economic incentives for CDR activities such as reforestation, improved forest management, forest products, bioenergy, DAC, and CO_2 storage in southern West Virginia and other disadvantaged communities in the state. ● Increase resources to provide technical assistance, and advise small forest, farmland, rangelands, and wetland owners on CDR activities at relevant West Virginia state agencies and West Virginia University and West Virginia State University Extension Services.

O	**Open CDR Opportunities While Protecting West Virginia's Ecology, Conservation, Economy, and the Environment:** Some CDR methods may have side effects that impact the state's ecology, conservation, economy, and environment. The West Virginia University team believes that the potential societal benefits of CDR outweigh the societal costs based on what we know today.	● Take steps to protect the economic health, human health, and ecology of local communities near CDR facilities and related CO_2 storage operations by
		  ● monitoring potential concerns;
		  ● improving the communities' environmental and ecological quality;
		  ● maximizing economic co-benefits; and
		  ● responding to unanticipated issues.

N	**Nurture West Virginia's Disadvantaged Communities** Socio-economically disadvantaged communities in West Virginia can benefit from CDR activities. However, care must be taken to ensure that past mistakes are not repeated by ensuring that local communities are involved in decision-making from the earliest stages and that they economically benefit from CDR investments.	● Facilitate access to federal, state, and non-profit CDR-related assistance programs for historically underserved communities to create economic opportunities and provide environmental, health, and safety protection. ● Require that CDR companies negotiate a community benefit agreement that includes the design and use of a community fund and addresses community concerns and recommendations from stakeholders (i.e., both landowners and non-landowners).

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Table of Contents

List of Tables, Figures, and Boxes

Executive Summary

Carbon, in its many forms, has long provided economic development opportunities for West Virginia. The nature of those activities has changed over time, and today West Virginia has a new opportunity to leverage the competitive advantage of its natural resources: by capturing carbon out of the ambient air. Proactive policymaker and stakeholder actions to capture this burgeoning opportunity in the near-term can place West Virginia in the lead of long-term carbon management markets. In this policymaker guide, we explore this opportunity and its potential in West Virginia.

What are the Potential Options for Carbon Dioxide Removal in West Virginia?

When we think about reducing atmospheric greenhouse gas concentrations, we typically focus on ways to ***reduce*** carbon dioxide (CO_2) and other greenhouse gases emitted from the residential, commercial, industrial, and transportation sectors. An alternative option is to ***remove*** the CO_2 that already exists in the atmosphere through carbon dioxide removal (CDR) methods. This policymaker guide focuses on the opportunities and challenges of implementing these CDR options in West Virginia.

As stated by the United Nations Intergovernmental Panel on Climate Change (IPCC), however, it's important to keep in mind that "the faster reduction of net CO_2 emissions in 1.5°C compared to 2°C pathways is predominantly achieved by *measures that result in less CO_2 being produced and emitted* [CO_2 reduction], and only to a smaller degree through *additional CDR* [CO_2 removal]" (emphasis added). In other words, CDR is not a panacea for responding to climate change but a mitigation tool that is necessary above and beyond strategies that prevent emissions of CO_2 and other greenhouse gases in the first place. As is often the case, prevention of a problem is far better and more cost effective than responding to the challenge after it occurs.

As illustrated in Figure ES.1, CDR relies very heavily on natural resources, including (1) forests, agricultural land, and wetlands, which capture carbon dioxide naturally, (2) forest and agriculture feedstocks to produce biofuels, bioproducts, and biopower, and (3) underground reservoirs and abandoned oil and gas wells to store the CO_2 that is captured through bioenergy with carbon capture and storage (BECCS) and direct air capture (DAC). Based on the West Virginia University (WVU) team's analysis, all of these resources are available in West Virginia, providing the state with the potential to be a major player in the evolving carbon management markets. Some of these resources are detailed below.

(1) **Forestland:** With about 12 million acres of forestland, West Virginia is the 3rd most forested state in the United States. Over half of this land is owned by small family foresters (10% of West Virginia's total population), 78% of whom wish to maintain their forests for future generations. Therefore, forest management methods can play a major role in capturing CO_2, maintaining our state's legacy of forest management.

(2) **Forest Products:** Forest products generate approximately $3.2 billion annually and employ more than 30,000 West Virginians across all 55 counties. West Virginia is 2nd in the United States in terms of standing hardwood forest area. The forest products industry plays an important role in CDR by facilitating CO_2 capture, providing the base

material for long-lasting wood products that can substitute for high-carbon-intensity materials like concrete and steel, storing CO_2 in buildings and furniture, and using any waste that it generates to create bioenergy.

(3) **Agricultural Crops and Soil:** West Virginia's agricultural industry (not including timber) contributes $800 million annually to the state's economy and grows crops that could store CO_2 or generate bioenergy (biopower and biofuels). Almost 70% of farms produce livestock or cultivate pastureland as their primary commodity. If managed properly, pastureland sequesters carbon in the soil. In addition, processing crop residue and livestock manure can result in renewable natural gas, which can reduce CO_2 with proper management and carbon capture and storage.

(4) **Wetlands:** Proper conservation, management, and restoration of West Virginia's inland wetlands can potentially store more CO_2 per acre than coastal wetlands while at the same time supporting West Virginia's tourism industry. For example, the wetlands of the Canaan Valley National Wildlife Refuge attract 73,500 annual visits, resulting in 33 jobs and roughly $2.7 million in economic benefit—mostly from out-of-town visitors.

(5) **CO_2 Storage:** DAC requires a geological location that can store any CO_2 that is not turned into products. Luckily, the same geology that supports West Virginia's fossil fuel industry, including former oil and gas reservoirs, unmineable coal seams, and saline formations, can potentially be used to store CO_2 and provide job opportunities for those in former coal communities.

One CDR method that we found would not work in West Virginia is carbon mineralization, as West Virginia does not have suitable geology for this method of capturing carbon.

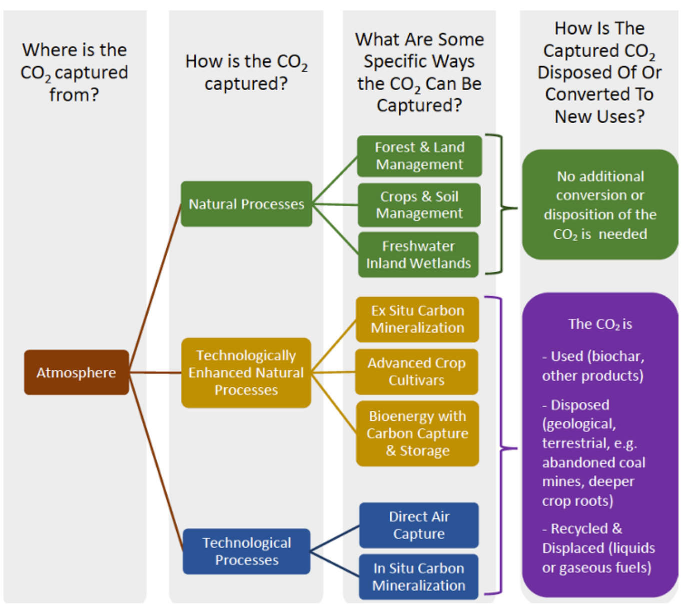

Figure ES.1. Carbon Dioxide Removal Possibilities in West Virginia (West Virginia University, 2022; adapted from Energy Futures Initiative, 2019)

How Much Carbon Dioxide Might be Removed from the Atmosphere in West Virginia?

Table ES.1 provides the WVU team's estimate of how much CO_2 can be removed from the atmosphere in West Virginia using each method, the cost per ton of CO_2 removed, and the annual investment that would be required. In 2019, West Virginia's energy-related CO_2 emissions were 85.4 million metric tons, according to the U.S. Energy Information Administration. The range of these emissions that could be removed in West Virginia, according to our analysis, is 3.8-30.0 million metric tons—4-35% of the state's total energy-related CO_2 emissions. The details of this analysis are provided in the appendices. Overall, however, it is important to understand that there is considerable uncertainty and variability in both the potential CO_2 removal and cost estimates.

Table ES.1. Potential CO_2 Removal, by Method, in West Virginia with Cost and Annual Investment Estimates (West Virginia University, 2022)

CDR Method	**Potential CO_2 Removal (million metric tons CO_2e/year by 2050)**	**Cost Estimate[1] (\$/ton CO_2e) 2025-2045**	**Annual Investment Estimate (million dollars/year)[2]**
Natural (forestland, crops, soil, and freshwater inland wetland management)	1.1-8.8	11-11	$12-97
Bioenergy with Carbon Capture and Storage (BECCS; new build)	2.7-13.2	120-96	$324-1267
Direct Air Capture (DAC)	0-8	243-201	$0-1608

Notes:

[1] Cost estimates are from the Lawrence Livermore National Laboratory Report (LLNL) Getting to Neutral: Options for Negative Carbon Emissions in California (2020). Cost is expected to decrease over time due to technological learning for BECCS and DAC, while there is sufficient knowledge about natural methods

based on their long-time implementation. For the DAC option, LLNL assumes that natural gas supplies the power as opposed to renewable energy options such as wind or solar, which require more space and monetary investment. Note, however, that the WVU team believes there is considerable uncertainty and variability in both the CO_2 removal and cost estimates.

[2] The lower-bound annual investment estimate is determined by multiplying the lower-bound estimates for both CO_2 removal and cost. Similarly, the upper-bound estimate is determined by multiplying the upper-bound CO_2 removal by the upper-bound cost estimate. Note that, in the case of both BECCS and DAC, some revenue might be generated from selling the products that result from these processes. In addition, the 45Q carbon oxide sequestration tax credit is already in place, and congressional proposals to modify that tax credit may subsidize the cost of these options. These estimates, however, were made without consideration of these credits.

What is the Potential Economic Impact if Carbon Dioxide Removal Methods Were Implemented in West Virginia?

An important factor in West Virginia is the potential economic impact CDR activities might have in the state—especially in its disadvantaged coal communities. Based on this information, Tables ES.2, ES.3, and ES.4 provide the economic contribution these investments would make to the state for natural, bioenergy, and DAC methods, respectively. The details of this analysis are provided in the appendices.

The U.S. Department of Energy's 2022 U.S. Energy and Employment Report estimated that West Virginia had 3,412 workers in electric power generation in 2021. The direct number of additional jobs in natural carbon would be 4-16% of current electric power generation employment, biomass to electricity would be 5-21%, biomass to fuels would be 2-10%, and DAC would be 0-51%.

Table ES.2. Annual Economic Impact of Natural Carbon Sequestration Efforts in West Virginia (West Virginia University, 2022)

	Direct Impact	**Indirect & Induced Impact**	**Total Economic Impact**
Output ($, millions)	12.2–54.6	6.0–26.7	18.2–81.3
Employment (jobs)	126–561	74–331	200–892
Labor Income ($, millions)	7.8–34.8	2.7–12.0	10.5–46.9
Total Taxes ($, millions)	0.7–3.2	0.3–1.1	1.0–4.3

Table ES.3. Annual Economic Impact of Biomass to Electricity Spending in West Virginia (West Virginia University, 2022)

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	276–1,094	170–675	446–1,770
Employment (jobs)	183–724	564–2,236	746–2,960
Labor Income ($, millions)	30–120	39–156	70–277
Total Taxes ($, millions)	5–19	4–17	9–36

Table ES.4. Annual Economic Impact of Biomass to Fuels Spending in West Virginia (West Virginia University, 2022)

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	99–512	36–185	135–697
Employment (jobs)	68–354	227–1,171	295–1,525
Labor Income ($, millions)	10–50	10–52	20–102
Total Taxes ($, millions)	1–5	1–5	2–10

Table ES.5. Annual Economic Impact of Direct Air Capture Spending in West Virginia (West Virginia University, 2022)

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	0–1,608	0–1,055	0–2,663
Employment (jobs)	0–1,740	0–4,662	0–6,402
Labor Income ($, millions)	0–254	0–269	0–523
Total Taxes ($, millions)	0–27	0–29	0–56

Notes for Tables ES.2 - ES.5:

1. Tax revenue impact includes sales, personal income, property, and corporation net income taxes.

2. For this study, we assume that all expenditures from carbon remediation will result in new, additional spending in the state's economy. We also assume that workers at these operations will live in West Virginia and spend their income similarly to the average West Virginia resident. All data for this study were provided to the Bureau of Business and Economic Research (BBER) by the WVU Carbon Dioxide Removal Working Group and were not independently audited by the BBER.

3. To estimate the economic impact of the carbon removal, we apply a detailed model of the West Virginia economy that outlines how trade-flows among industries interact with key economic indicators such as employment, income, output, and tax revenue. The annual expenditures for carbon-removal measures are referred to as the direct economic impact. However, the total economic impact of these activities is not limited to the direct impact but also includes secondary economic impacts accrued as those initial direct expenditures are re-spent across the state, generating a multiplier effect throughout the rest of the state's economy.

4. Because biomass to electricity and fuel uses the same feedstock, the numbers cannot be added to develop a total jobs estimate from all the options in Tables ES.2-ES.5.

5. Due to the varying degrees of uncertainty associated with each CDR option, it is important to note that these estimates are ranges.

What are the Potential Challenges in Implementing Carbon Dioxide Removal in West Virginia?

Implementing CDR in West Virginia involves a number of challenges. A list of the potential environmental challenges is provided in Table ES.6. In addition, in order for BECCS and DAC to be economically feasible, co-location of these facilities near sites for storing CO_2, selling bioenergy (electricity generation, fuel), or utilizing CO_2 in manufactured products is important. There will likely be competition within West Virginia for locations that could become CO_2 sequestration hubs from the current fossil fuel, petrochemical, and other manufacturing industries as well as a possible hydrogen hub. As a result, co-location becomes challenging because everything is driven by CO_2 storage availability or utilization. If co-location is not available, then the costs for BECCS and DAC can quickly escalate beyond what is economically feasible.

Table ES.6. Potential Environmental Challenges in Implementing CDR

CDR Option	Potential Environmental Challenges
Forestry	• Lack of consideration for local conditions in reforestation management practices can result in poor outcomes and decreased biodiversity, especially on previously mined lands. • Afforestation may require fertilizers which could make their way into local water systems. • Managing forests primarily for carbon removal can compete with other conservation efforts, such as creating habitat for native plants and wildlife.
Agriculture	• Additions of fertilizer materials, including manure, can contaminate local water systems. • Conversion of land to agriculture typically reduces local biodiversity and wildlife habitat, negatively impacts stream quality, and can lead to increased

	invasive species.
Wetlands	• If not properly restored or created, wetland restoration failures can lead to more erosion, invasive species colonization, over-abundance of predators, and other ecological challenges. • Depending on their hydrology (movement of water), restored wetlands could release methane (CH_4), which is a potent greenhouse gas.
Bioenergy with Carbon Storage	• Without sustainable water management practices, there is a potential of limiting freshwater and decreased groundwater availability. • Monoculture of crops results in reduced biodiversity and resilience.
Direct Air Capture	• Construction of storage sites may result in net gains to CO_2 and can negatively impact local air and water quality.
Carbon Storage	• Underground storage may result in changes to groundwater chemistry, potentially impacting drinking water systems drawn from local wells. • Potential leakage from geologic reservoirs poses concerns for local communities.

What are the Findings and Recommendations Regarding Carbon Dioxide Removal in West Virginia?

Based on a review of the literature and consultation with experts in the field, the WVU team developed a number of findings and policy options. The team then analyzed each policy option, examining its effectiveness (ability to achieve the societal goal), efficiency (best "bang for the buck"), equity ("consistent and systematic fair, just, and impartial treatment of all individuals"), and ease of political acceptability (degree of support or opposition among key players) in West Virginia. Note that the results of this "4E" analysis may differ in other geographic areas.

The team then provided the draft of this policymaker guide including its findings and policy options at three stakeholder roundtables held in August and September 2022 (see Appendix C for details). The stakeholders provided feedback on the findings and policy options during each roundtable discussion, and following the event we asked them to identify the policy options they thought should have the highest priority based on the same 4E criteria. This resulted in a "top 10" recommendation for the policy options (with no order amongst these options). The WVU team agreed with this top 10 list.

The results are presented as the policymaker guide's findings and recommendations provided in Table ES.7.

Table ES.7. West Virginia University Bridge Initiative Carbon Dioxide Removal (CDR) and West Virginia Findings and Top Ten Recommendations (West Virginia University, 2022)

	Findings	Top Ten Recommendations (not in priority order)
C A	**Create Carbon Reduction Opportunities in West Virginia** **Finding 1:** West Virginia has the most scientific and technological carbon reduction potential for CDR options using natural methods (such as forests, agriculture, wetlands, and forest products, which can be implemented immediately) as well as bioenergy with carbon capture and sequestration (BECCS) (which can take varying amounts of time depending on the technology chosen) and direct air capture (DAC) (which requires additional time for the development of appropriate carbon sequestration pathways). Carbon mineralization is not an option due to the state's geology. Whatever CDR options are chosen, care should be taken to establish appropriate standards and verification processes.	**Recommendation 1**: Work with federal agencies (U.S. Department of Energy (DOE) and U.S. Department of Agriculture (USDA)) and leading nongovernmental organizations to develop appropriate standards for net carbon accounting of stored and sequestered carbon. **Recommendation 2:** The USDA, working with the DOE, should request to fund a study by the National Academies of Science, Engineering, and Medicine (NASEM) to determine the optimal harvest cycle for maximizing the carbon removal potential by forests and forest products. The study should also consider the ecological factors (e.g., the role trees play in mitigating flooding), social factors (e.g., landowner goals), and economic factors (e.g., life cycle analysis of wood products and impact on the forest products industry).
R	**Restore Carbon into West Virginia's Natural Resources** **Finding 2**: The chief challenge for the implementation of BECCS and DAC options is developing a better understanding of the ability to store CO_2 in West Virginia. There are many possible locations, but site-specific analysis and demonstration projects are needed to assess the technical viability of carbon storage options for BECCS and DAC.	**Recommendation 3:** Incorporate BECCS into the existing U.S. Renewable Fuel Standard. **Recommendation 4:** Fund a study that examines both community and technical opportunities and challenges to identify suitable locations for DAC demonstration projects in West Virginia. This study, perhaps funded by the new DOE Office of Clean Energy Demonstrations, should include financial support for the creation and maintenance of community infrastructure (e.g., roadways, water, and noise prevention) that might be impacted by DAC development and operations.
B	**Benefit West Virginia's Economic Prosperity and Create Jobs for West Virginians** **Finding 3:** CDR has the potential to generate economic prosperity and job creation, particularly in West Virginia's coal communities and other rural communities. The natural options are in rural areas and abandoned mine lands, while potential carbon storage sites for DAC are near the hardest-hit coal communities in southern West Virginia as well as oil and gas reservoirs throughout the state.	**Recommendation 5:** Invest in economic incentives for CDR activities such as reforestation, improved forest management, forest products, bioenergy, DAC, and CO_2 storage in southern West Virginia and other disadvantaged communities in the state. **Recommendation 6:** Increase resources for the West Virginia Department of Commerce's Division of Natural Resources (WVDNR) and Division of Forestry (WVDOF) as well as the West Virginia Department of Agriculture (WVDA) to provide technical assistance and advise small forest, farmland, rangeland, and wetland owners on the economic potential and participation details of carbon credit or offset programs and markets.

		Recommendation 7: Increase resources for West Virginia University (WVU) Extension and West Virginia State University (WVSU) Extension and outreach representatives from colleges and universities throughout the state to advise small forest, farmland, and wetland owners on the economic potential of carbon credit and details of participation. In addition, the West Virginia Department of Environmental Protection (WVDEP) should prioritize and accelerate its Wetland Rapid Assessment to identify wetlands to preserve and restore.
O	**Open CDR Opportunities While Protecting West Virginia's Ecology, Conservation, Economy, and the Environment** **Finding 4:** Some CDR methods may have side effects that impact the state's ecology (living organisms), conservation (natural resources), economy (jobs), and environment (air, water, soil). Taking into account both the opportunities and challenges of each CDR option, the West Virginia University team believes that the potential societal benefits outweigh the societal costs based on what we know today. This assessment is based on a presumption that care is taken to protect local communities.	**Recommendation 8:** Take steps to protect the economic health, human health, and ecology of local communities near CDR facilities and related CO_2 storage operations by ● monitoring potential concerns; ● improving the communities' environmental and ecological quality (e.g., drinking water, reforestation, and wildlife habitats); ● maximizing economic co-benefits; and ● responding to unanticipated issues that arise including, but not limited to, economic harm and environmental degradation.
N	**Nurture West Virginia's Disadvantaged Communities** **Finding 5:** Socio-economically disadvantaged communities in West Virginia can benefit from CDR activities. However, care must be taken to ensure that past mistakes are not repeated by ensuring that local communities are involved in decision-making from the earliest stages and that they economically benefit from CDR investments.	**Recommendation 9:** Facilitate access to federal, state, and non-profit CDR-related assistance programs for historically underserved communities to create economic opportunities and provide environmental, health, and safety protection. **Recommendation 10:** Require that CDR companies negotiate a community benefit agreement that includes the design and use of a community fund and addresses community concerns and recommendations from stakeholders (i.e., both landowners and non-landowners).

Participating West Virginia University Faculty, Staff, And Students

This policymaker guide was developed by the WVU faculty, staff, and students listed below under the Bridge Initiative for Science and Technology Policy, Leadership, and Communications, directed by Joan Centrella. Eddie Brzostek, Shikha Sharma, John Deskins, Dave McGill, and Jamie Shinn led the working groups that developed the content for this guide. Deborah Stine was the study director as a consultant to WVU, and Brooke Eastman was the Bridge Postdoctoral Science Policy Fellow, who was a major contributor to the policymaker guide.

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1: Introduction

Responding to climate change through mitigation and adaptation is now recognized as being essential to the global plan to reduce the impact of climate change on society. These approaches are defined as follows by the United Nations Intergovernmental Panel on Climate Change (IPCC):

- Mitigation is "a human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs)."
- Adaptation is "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects."

In our previous policymaker guide, The Waters of West Virginia: A Science and Technology Policy Perspective, we discussed ways in which West Virginia could adapt to the impact of climate change, particularly extreme precipitation events that could lead to flooding. In this guide, we are focusing exclusively on the removal of carbon dioxide (CO_2) from the atmosphere—that is, on human interventions that can "enhance the sinks" for CO_2—and on policies to support such interventions in West Virginia. As noted by the IPCC, such actions will likely be needed to respond to climate change (see Box 1.1).

The National Academies of Sciences, Engineering, and Medicine (NASEM) recommends atmospheric carbon dioxide removal (CDR) options using natural processes to increase CO_2 storage in forests, agricultural lands, and wetlands, as well as storage of CO_2 captured from biomass, direct air capture, and enhanced rock weathering. West Virginia's natural resources and skilled workforce provide a unique opportunity to contribute to CDR while enhancing West Virginia's economic prosperity as these new markets emerge.

The purpose of this study is to provide information for policymakers that will help them understand both the opportunities and challenges of CDR activities in West Virginia. The West Virginia University (WVU) faculty and staff who developed this guide focused their efforts on answering the following questions:

1. What are potential scientific and technological opportunities and challenges to the removal and storage of CO_2 from the atmosphere in West Virginia?
2. How could the effective and efficient removal and storage of CO_2 from the atmosphere enhance economic prosperity and job creation in West Virginia?
3. What are potential new ecological, conservation, and environmental opportunities and challenges to the removal and storage of CO_2 from the atmosphere in West Virginia?
4. What are the associated opportunities, challenges, risks, and empowerment potential for traditionally socio-economically disadvantaged communities, including communities of color and those located in former coalfields?
5. What actions, if any, should national, state, and local West Virginia policymakers take to enhance the removal and storage of CO_2 from the atmosphere to reduce climate variation, increase economic opportunities, and create jobs for West Virginians?

Box 1.1. The Intergovernmental Panel on Climate Change (IPCC) on "The Role of Carbon Dioxide Removal (CDR)"

"***All analysed pathways limiting warming to 1.5°C with no or limited overshoot use CDR to some extent to neutralize emissions from sources for which no mitigation measures have been identified and, in most cases, also to achieve net negative emissions to return global warming to 1.5°C following a peak (high confidence). The longer the delay in reducing CO_2 emissions towards zero, the larger the likelihood of exceeding 1.5°C, and the heavier the implied reliance on net negative emissions after mid-century to return warming to 1.5°C (high confidence).*** The faster reduction of net CO_2 emissions in 1.5°C compared to 2°C pathways is predominantly achieved by measures that result in less CO_2 being produced and emitted, and only to a smaller degree through additional CDR. Limitations on the speed, scale and societal acceptability of CDR deployment also limit the conceivable extent of temperature overshoot. Limits to our understanding of how the carbon cycle responds to net negative emissions increase the uncertainty about the effectiveness of CDR to decline temperatures after a peak. {2.2, 2.3, 2.6, 4.3.7}

"***CDR deployed at scale is unproven, and reliance on such technology is a major risk in the ability to limit warming to 1.5°C. CDR is needed less in pathways with particularly strong emphasis on energy efficiency and low demand. The scale and type of CDR deployment varies widely across 1.5°C pathways, with different consequences for achieving sustainable development objectives (high confidence).*** Some pathways rely more on bioenergy with carbon capture and storage (BECCS), while others rely more on afforestation, which are the two CDR methods most often included in integrated pathways. Trade-offs with other sustainability objectives occur predominantly through increased land, energy, water and investment demand. Bioenergy use is substantial in 1.5°C pathways with or without BECCS due to its multiple roles in decarbonizing energy use. {2.3.1, 2.5.3, 2.6.3, 4.3.7}"

What is Carbon Dioxide Removal?

Much of the response to climate change focuses on mitigation of greenhouse gas emissions, primarily CO_2, from point sources such as power plants, transportation, and industrial facilities. CDR takes a different approach by removing legacy CO_2 from ambient air and storing it. This does not mean that mitigation actions are unnecessary. Although the fastest climate change mitigation pathways focus predominantly on lessening the production and emission of CO_2 (Box 1.1), the IPCC notes that CDR can supplement mitigation actions, particularly in cases where greenhouse gases are especially difficult to mitigate with today's technologies, as in aviation, steel production, and agriculture.

In West Virginia, there are three ways CO_2 can be captured from the ambient air: by natural processes, by technologically enhanced natural processes, and by technological processes (see Figure 1.1).

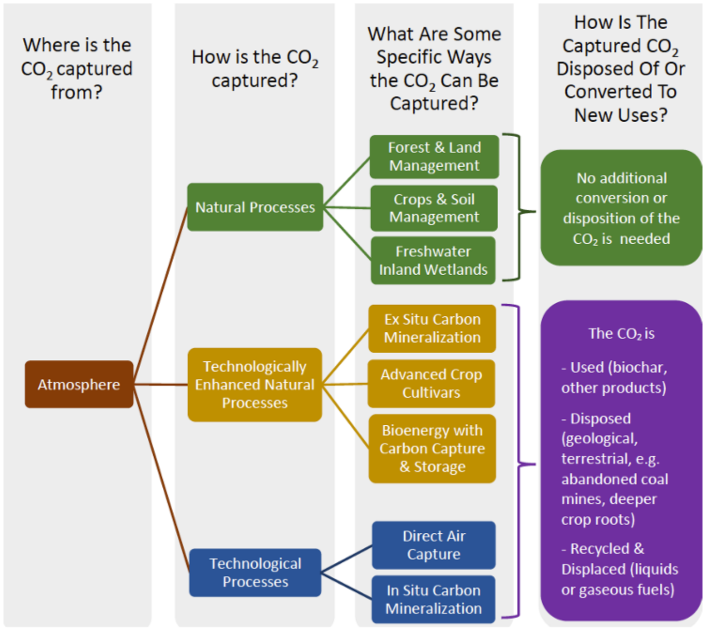


Figure 1.1. Carbon Dioxide Removal Possibilities in West Virginia (West Virginia University, 2022; adapted from Energy Futures Initiative, 2019)

Natural Processes

Natural CDR involves managing ecosystems such as forests, agriculture, and inland wetlands to encourage maximum CO_2 sequestration in each natural system. Such management strategies take advantage of the natural carbon cycle in which plants remove (sequester) CO_2 from the atmosphere and store it both above ground (in trees, crops, and wetland vegetation) and below ground (in soils, roots, and wetland peat and sediments). This process is described in Figures 1.1 and 1.2. In addition, some of the carbon in trees harvested from forests may be used to produce long-lasting wood products (e.g., hardwood flooring, furniture, residential construction). Stand-management practices in forests, such as thinning, can also alleviate competition in overly dense stands, which may help create forests that are more resilient to changes in climate and disturbances. An advantage of optimizing these natural processes and products is that the "infrastructure" for carbon storage (i.e., the plants, soils, and wood products supply chain) is already in place, while other CDR processes require new infrastructure for the disposal and long-term storage of sequestered carbon. Long-term storage of carbon in plants, soils, and wood products requires ongoing management, and protection from disturbances (e.g., climatic stressors, insect pests, fungal pathogens, fire) is required to conserve the additional carbon stored in plants and soils.

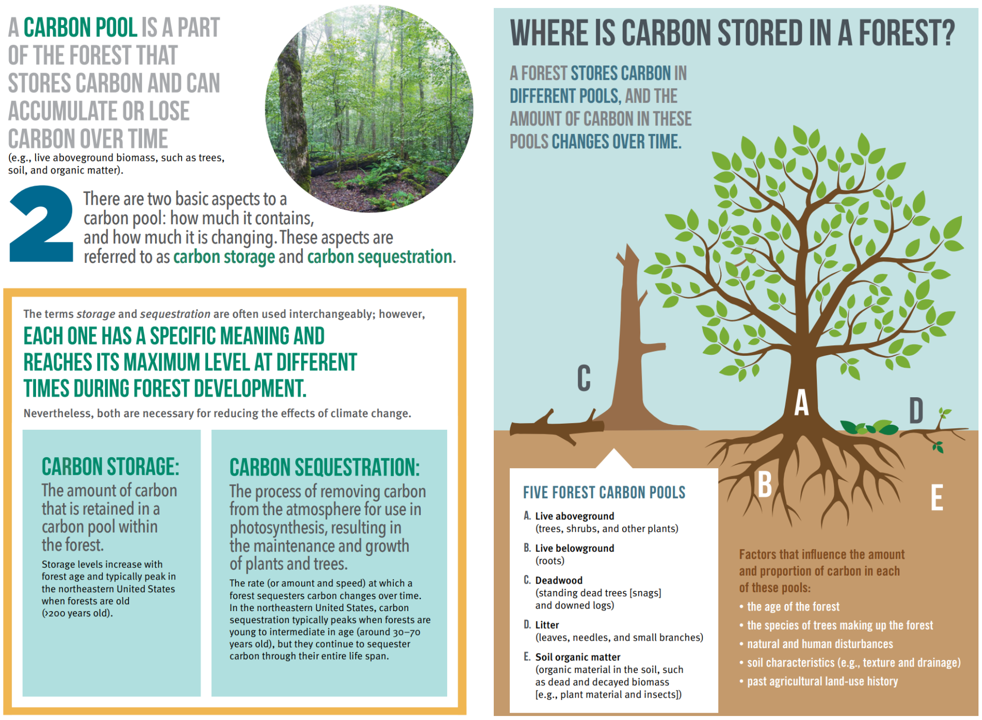


Figure 1.2. Definitions of Carbon Sequestration and Storage in Natural Ecosystems Such as Forests, Croplands, and Wetlands (left) and Conceptual Diagram of the Major Carbon Pools in a Forest (right) (University of Amherst, 2019)

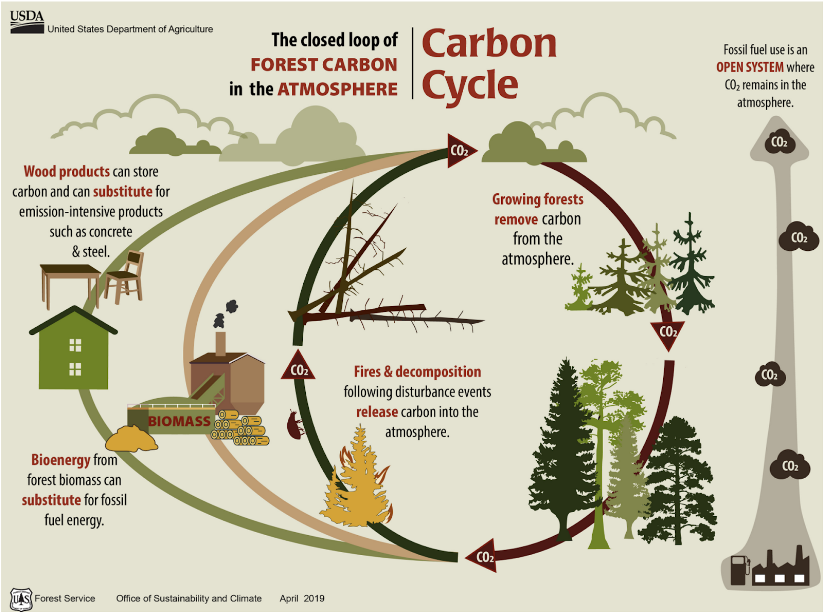


Figure 1.3. Closed Loop of Forest Carbon in the Atmosphere: Carbon Cycle (U.S. Department of Agriculture, 2021) *Three pathways of forest carbon returning to the atmosphere are depicted: via wood products (light green arrow), biomass energy (tan arrow), and the natural forest carbon cycle (dark green arrow). This carbon may then be sequestered back into the forest as trees grow (brown arrow). By contrast, the fossil fuel system only releases carbon into the atmosphere (gray arrow) and does not draw carbon out of the atmosphere.*

For forests, this approach to CDR involves managing the forest carbon cycle (Figure 1.3) to optimize how much carbon is sequestered and stored long-term. Approximately 78% of West Virginia's land area (12 million acres) is forested, offering a major natural resource asset for the state. While the wood products industry brings more than $3 billion to West Virginia each year, about half of the forested land in West Virginia (6.3 million acres) is owned by small family forest owners (Figure 1.4) who are more interested in preserving their forest than harvesting timber on their land but may not have management plans. As a result, forest management for CDR on private family forest lands offers an additional revenue opportunity to the state and to West Virginia land owners. Some businesses and nonprofits, such as the West Virginia Nature Conservancy and the American Forest Foundation, are working to help West Virginians take advantage of these economic opportunities by assisting small forest owners with forest management plans and subsequent opportunities to participate in carbon credit programs, as well as advising large forest owners on sustainable forest product production. Box 1.2 describes how forest carbon offset programs work.

Box 1.2. What are Forest Carbon Offset Programs and How Do They Work?

“The management of the entire forest resource is important when it comes to diversifying and strengthening the state’s forest-based industries. Ecological services that are not always included in forest-based industries portfolio must be incorporated in future development if the wood products industry is to remain vibrant. Many of these services are not well known by traditional industry executives or private landowners; however, their importance to the public cannot be understated.

“One of the most visible of these services is the carbon sequestration capacity of hardwood forests. Carbon sequestration is the process through which carbon dioxide (CO_2) from the atmosphere is absorbed by trees through photosynthesis and stored as carbon in woody biomass (tree roots, trunks, branches, and foliage). Sequestration of carbon by forest ecosystems enhances the quality of soil, water, and air. This has become increasingly important due to the impacts of global warming on the world’s environment. Sequestration of carbon by forested ecosystems can offset the amount of greenhouse gases released into the atmosphere, thus potentially reducing the global climate change.

“The monetary relevance of sequestration to the forest-based industry is through carbon offsets or credits. Market mechanisms have been implemented that give forest landowners the opportunity to “sell” the CO_2 that their trees sequester to those that produce excessive amounts of CO_2 who need or want to “offset” their emissions. There are several forestry project types that qualify under offset programs. These include forestation (afforestation and reforestation), forest management, and avoided deforestation (preservation). Each of these project types has a number of criteria that must be met in order to qualify for the program. For instance, in forest management project, landowners must:

- Have a current forest inventory
- Use approved forest management practices
- Commit to positive sequestration of carbon and maintaining sustainability certification
- Maintain the integrity of inventory over time through re-inventory and reporting of removals and additions
- Be willing to open land for verification process

“All types of forest carbon credit transactions require certification through a third-party system such as the Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI), and the American Tree Farm Program. Carbon credits are traded primarily on two exchanges: the Chicago Climate Exchange and the California Climate Registry. Credits are traded over the counter; this includes unmonitored transactions between two parties. Currently the market is highly variable and transactions among the different exchange types have ranged from $1.80 to $300 per ton CO_2 equivalent, with a 2018 article suggesting that an annual credit price of $12 per acre per year is typical (Bullinger, 2018).

“The use of carbon credits to provide annual returns to the landowner from their forestland investment should be explored and promoted within the state with particular emphasis on gaining access to this opportunity to landowners who own less than 500 acres to enroll in the program. Landowners might be more willing to participate in a carbon credit program if they were given the chance to participate with other landowners in the area in some type of cooperative effort that would promote more of an economy of scale than is typically available for an individual landowner with less than 500 to 1000 acres of forestland available for enrollment."

Source: West Virginia's 2020 Statewide Forestry Plan, 2020

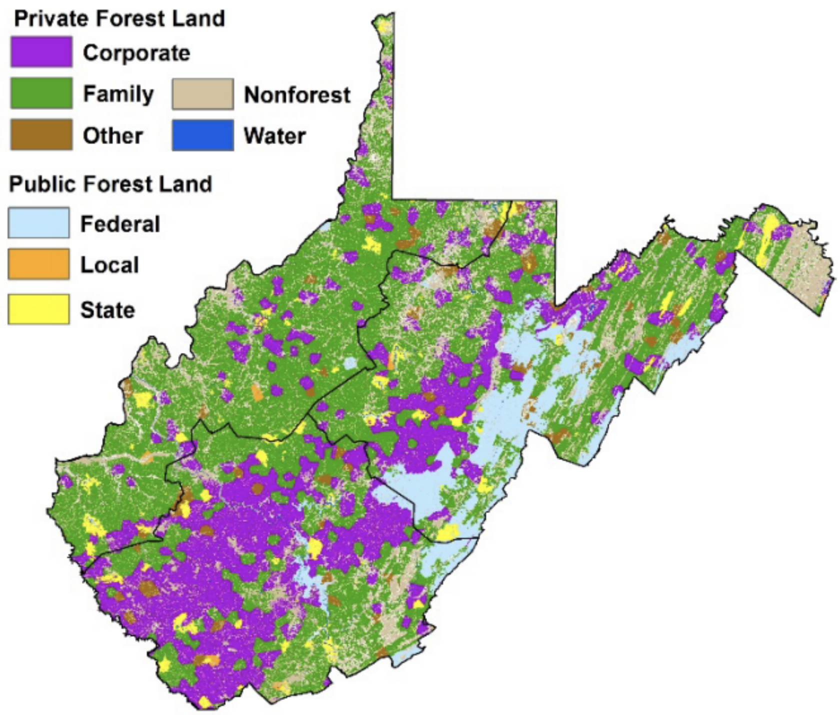


Figure 1.4. West Virginia Forestland, by Owner (U.S. Department of Agriculture, 2016)

Agricultural management that increases the amount of carbon stored in the soil is another natural CDR method with potential in West Virginia. West Virginia has 3.5 million acres of farmland spanning 22,800 farms, 98% of which are family-owned farms. Figure 1.5 depicts how CDR by agriculture involves practices that increase the carbon sequestered by plants and stored in soil. These practices may take place on traditional crop production systems for human consumption, bioenergy crop production, or pastureland and grazing land systems. Specifically, agricultural management practices that increase plant productivity, improve plant resilience, promote plant diversity and deep-rooted crops, and increase perennial crop rotations can increase carbon removal from the atmosphere and carbon transfer to the soil by plants.

Additionally, agricultural practices aimed at reversing and preventing erosion, limiting disturbances such as tillage, and growing plants on marginal lands (e.g., abandoned mine lands in the case of West Virginia) can promote soil carbon storage.

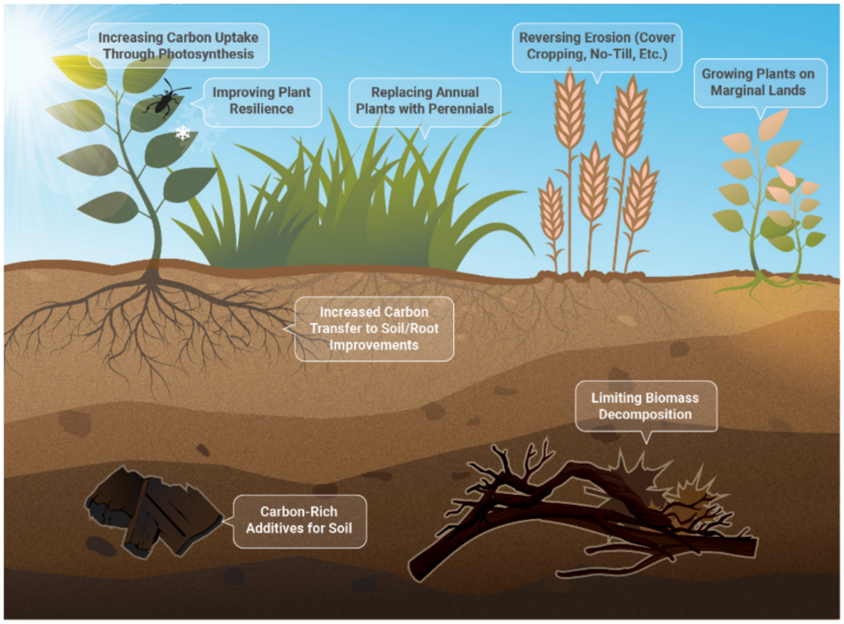


Figure 1.5. Biological and Terrestrial CDR Pathways (Energy Futures Initiative, 2020)

A third option for natural carbon removal in West Virginia is restoration of inland wetlands. Figure 1.6 illustrates how wetlands can sequester carbon. A global study of wetlands found that inland wetlands can potentially store ten times more carbon per acre than coastal wetlands. West Virginia is in the process of updating its wetlands map, which has not been updated since the 1980s (Figure 1.7).

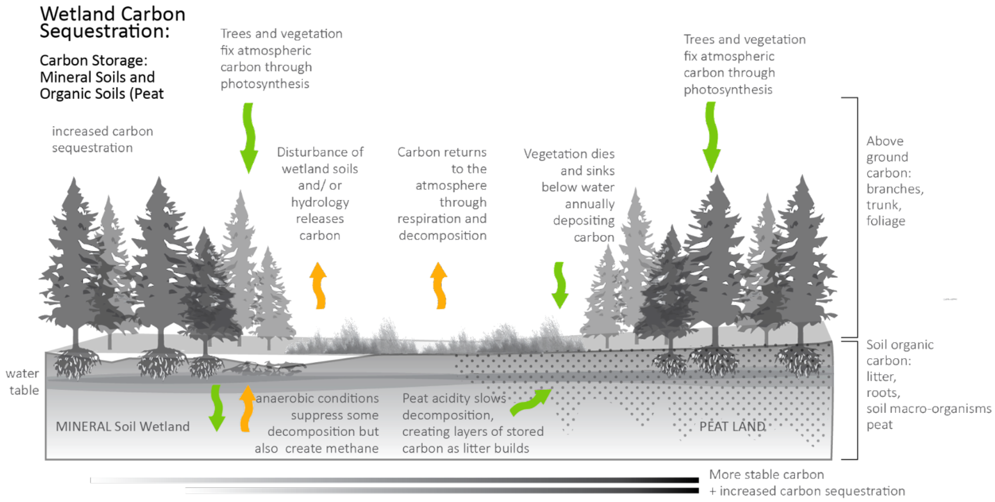


Figure 1.6. Wetland Carbon Sequestration ([Minnesota Board of Water and Soil Resources](), 2021)

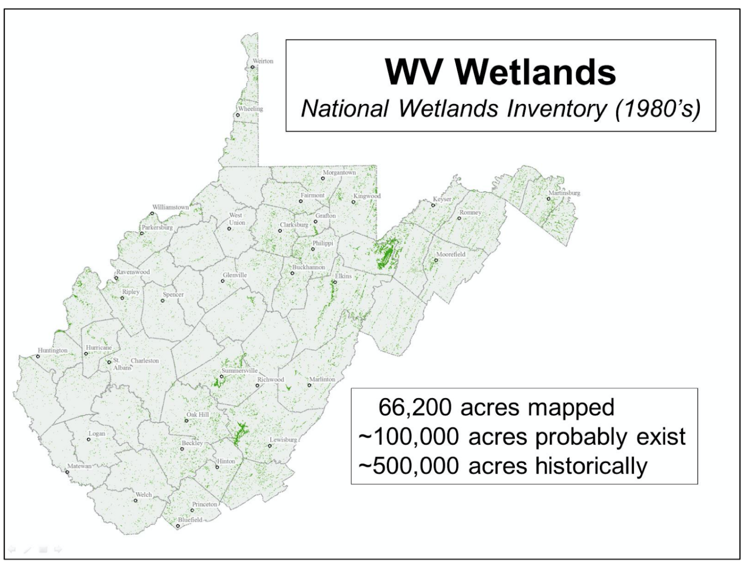


Figure 1.7. West Virginia Wetlands (West Virginia Departments of Natural Resources and Environmental Protection, 2021)

Technologically Enhanced Natural Processes

A hybrid approach brings together natural processes and technology. For example, two technologies currently in the development phase–advanced crop cultivars and carbon mineralization–enhance natural processes of plant growth and rock weathering so more carbon can be absorbed. While these technologies are still being developed, actions can be taken to promote their development and prepare to employ them once they become available. A third technology, bioenergy with carbon capture and storage technology (BECCS), uses specific crops or biological waste (e.g., plant residues, wood) as fuel to produce energy. In BECCS, the carbon emissions from combusting the plant matter are captured and stored (see section 5 and later discussion of forest products) before they enter the atmosphere.

Advanced crop cultivars with deeper roots are being developed through conventional breeding and using biotechnology techniques to achieve greater soil carbon sequestration. Plants draw CO_2 out of the atmosphere through photosynthesis and use the carbon to build plant tissues and feed soil microbes. The carbon sent below ground by plants through roots and other soil inputs can become stabilized in the soil and increase the soil carbon sink. Other possible applications of biotechnology for the purpose of enhanced carbon sequestration include converting annual plants to perennial plant systems, modifying plants to be able to grow on marginal lands, and modifying trees to increase the resilience and carbon sequestration of forests. However, these applications are unlikely to be developed in the next 5-10 years. Additional concerns include the ethical, legal, and social implications of biotechnology used for this purpose and the use of genetically modified organisms, which are regulated in some countries.

Carbon mineralization is the natural process of weathering igneous or metamorphic rock, where CO_2 reacts with certain types of rocks to become a solid material, such as carbonate (Figure 1.8). Recent research has focused on accelerating the process of rock weathering and, thus, CDR. Though still being developed, certain methods such as increasing the concentration of CO_2 that is exposed to rocks, increasing the surface area of rocks that react with CO_2 (by crushing the rocks), and controlling some of the environmental conditions (pH and temperature) have been shown to increase the rate of CDR by carbon mineralization. This process can occur either *in-situ* (without removing the rocks from their original location) or *ex-situ* (relocating rocks to a new location).

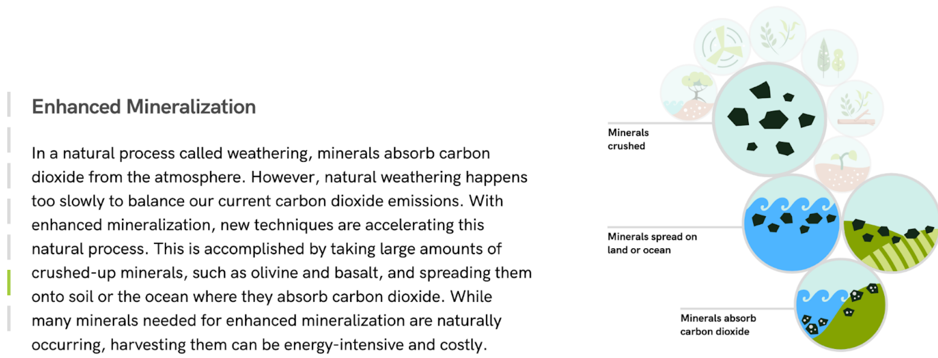


Figure 1.8. How Enhanced Mineralization Works (adapted from Chan Zuckerberg Initiative, 2022)

A third technologically enhanced approach to CDR is bioenergy with carbon capture and storage (BECCS), where specific crops grown exclusively for bioenergy (e.g., corn, miscanthus, switchgrass, poplar) or biological waste products (e.g., crop residue, wood, manure) are combusted to generate electricity (Figure 1.9). The CO_2 generated as a result is then captured and stored underground. With appropriate soil amendments, some bioenergy crops, such as switchgrass and poplar, can be grown on abandoned mine lands. Deep-rooted perennials like switchgrass can sequester a lot of carbon belowground, building up the soil on marginal lands while producing biofuel. Switchgrass grown on a reclaimed mine in West Virginia produces 3-6 tons per acre annually, which can be used in electricity production or livestock feed. Additionally, West Virginia's economic activity in agriculture and forestry results in biological waste that can be used in BECCS, such as wood pulp from the wood products industry. BECCS can replace some of the declining demand for wood byproducts from other industries (such as the paper industry).

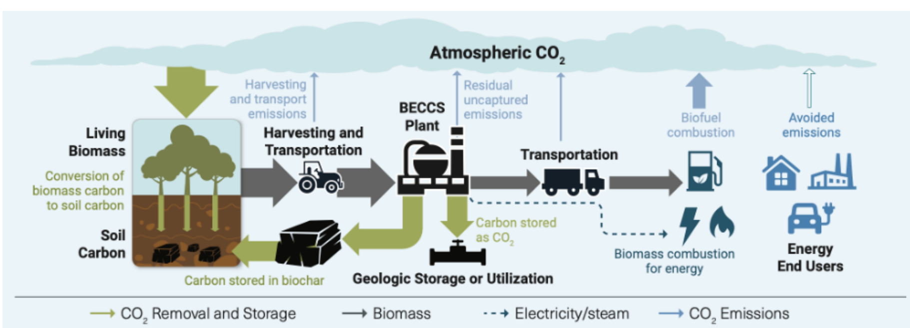


Figure 1.9. Carbon Flows from BECCS (Energy Futures Initiative, 2022)

Technological Processes

Technological processes involve *in situ* carbon mineralization and direct air capture (DAC). As shown in Figure 1.10, DAC captures the CO_2 from ambient air that enters an air contactor, which is then either stored underground, utilized to create products (e.g., cement, chemicals), or used for enhanced oil recovery.

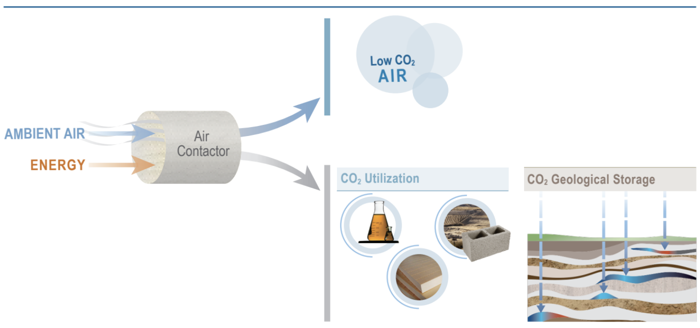


Figure 1.10. Direct Air Capture of Carbon Dioxide (Global CCS Institute, 2018)

The primary challenge regarding DAC from a CO_2 removal perspective is that the energy used to power the air contactor (Figure 1.11) and the ultimate use of the CO_2 need to be such that overall carbon dioxide emissions are reduced. The power, therefore, needs to come from non-carbon polluting sources such as renewable energy. The amount of wind or solar energy needed to power a DAC is quite high, and therefore sufficient surface area is needed near the DAC facility, which limits location options. Geothermal energy is another potential power source, but there are limited areas where it is available. Natural gas is yet another possibility, but as a fossil fuel, it generates CO_2; the question in this case is whether more CO_2 is captured than emitted from its use.

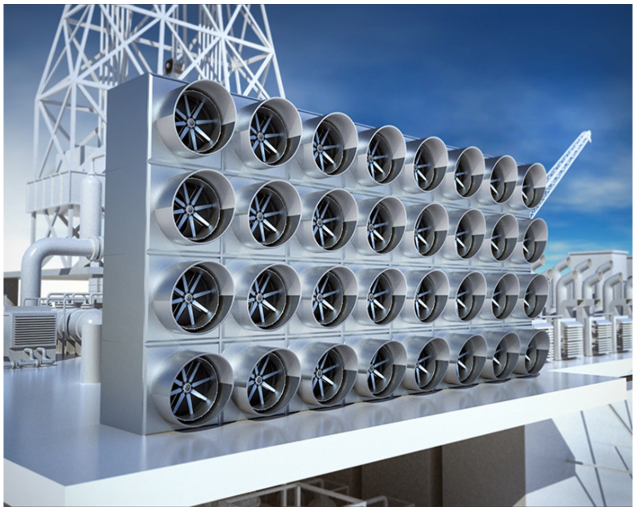


Figure 1.11. Direct Air Capture Contactor (National Energy Technology Laboratory, 2022)

Another challenge with DAC is determining how the captured CO_2 is to be managed. If the CO_2 is stored underground, the DAC facility will need to be located near feasible areas for storage where it will not escape and where the storage will not run out. If the CO_2 is turned into a product, like cement, then there needs to be a way to fully utilize it. If it is used for chemical production, it needs to be located near a production facility, or a new facility needs to be built near the DAC location to avoid the public opposition and environmental and safety concerns related to building pipelines to transport CO_2.

Several DAC facilities are beginning to emerge globally, and we will learn more about their operation over the next few years. The National Energy Technology Laboratory (NETL), located in West Virginia, held a meeting in February 2021 to kick off its DAC research and development activities.

What Economic Opportunities and Challenges Should be Considered When Assessing CDR Activities?

Today, economic opportunities for CDR activities fall into three categories:

- **Economic incentives from federal organizations.** Federal policies provide economic incentives for CDR-related actions. For example, the USDA has incentive programs to encourage farmers to leave crop residue undisturbed (called "no till") between plantings, which reduces CO_2 emissions. In addition, tax code section 45Q provides tax credits for some (but not all) CO_2 removal activities.

- **Economic incentives from other organizations.** Some companies, universities, and other organizations may provide economic incentives for CDR activities, including carbon "offsets" and "insets" (Box 1.3).
    - Carbon offsets allow corporations or individuals to account for some of their direct emissions by purchasing carbon credits from others who are sequestering carbon. They do not result in net emissions reductions but simply "offset" some of their emissions.
    - Insets are absolute emissions reductions that do not allow emissions to increase elsewhere. Insets must be achieved within a corporation's supply chain (i.e., they cannot come from another sector) rather than be attributable to their direct GHG emissions. Typical nature-based insetting interventions include natural systems agriculture and climate adaptation, regenerative agriculture practices, and protecting and restoring forests and wetlands.
- **Infrastructure investments, including those for green infrastructure.** In CDR, this can include man-made engineered infrastructure like a DAC facility or a bioenergy plant, as well as green infrastructure that promotes reforestation and wetlands restoration. In this case, the federal government, companies, or both invest in demonstration facilities as an initial step and ideally make long-term investments in full-scale facilities. In both cases, new business and family-supporting employment opportunities may result.

All of these possibilities could provide revenue options for blue-collar, white-collar, and entrepreneurial West Virginians who participate in CDR activities. This potential may be important in a state that faces economic challenges. One estimate for DAC, for example, identifies 3,500 well-paying jobs per DAC facility, including jobs in construction, engineering, equipment manufacturing, cement, steel, chemical, and natural gas throughout the supply chain, as well as long-term operation and maintenance jobs in the communities where facilities are located.

Box 1.3. Carbon Offsetting vs. Insetting

The following information, from the World Economic Forum, explains the difference between carbon offsetting and carbon insetting:

Carbon Offsetting

"Private sector companies are increasingly relying on voluntary offsetting by means of carbon credits to get to carbon-neutral status. For example – company A could offset its unavoidable emissions by purchasing carbon credits from company B that is in the business of, or uses, renewable energy. Company B in exchange would set up a new solar plant or a new wind farm. In this case, B benefits from clean energy and A from its reduced carbon footprint.

"Alternatively, company A could pay company C for carrying out reforestation initiatives. In this case, company A has once again offset its emissions in the environment, and in exchange, company C has helped protect biodiversity and create jobs for the indigenous communities that will look after the forests.

"However, despite the simple nature of this exchange, some crucial factors such as double-counting and additionality have the potential to reverse the impact of carbon markets from positive to negative. Example: company A pays company B for the offset project (renewable power) and both entities count the emissions reduced in their respective books – this is known as double counting. Similarly, company A pays company C for reforestation initiatives that were slated to happen anyway – this would be considered additionality.

“There is, therefore, an urgent need for companies and countries alike to identify high integrity projects that adhere to robust climate methodologies.”

Carbon insetting: “doing more good rather than doing less bad”

“While the world grapples with the impending challenge of getting to net-zero by 2050, companies and countries will inevitably incorporate the use of carbon offsets. The battle with soaring temperatures will, however, not be won until organizations start decarbonising their own value chains to include more nature-positive solutions and operations. Put in simple words, carbon ‘insetting’ focuses on doing more good rather than doing less bad within one’s value chain.

“As explained by the International Platform for Insetting, with the aim of slashing GHG emissions from one’s own supply chain, insetting is the implementation of nature-based solutions such as reforestation, agroforestry, renewable energy and regenerative agriculture. Some insetting activities also improve the livelihoods of indigenous communities as a result.”

Source: Explainer: Carbon Insetting vs. Offsetting, World Economic Forum, May 18, 2022

What Equity Issues Should be Considered When Assessing CDR Activities?

When analyzing potential policies, one criterion is equity. Box 1.4 offers definitions of “equity” as well as “underserved communities” from President Biden’s Executive Order 13985. Note that the term “equity” includes not only persons of color (less than 10% of West Virginians) but also “persons who live in rural areas” (most West Virginians; definitions differ) and “persons otherwise adversely affected by persistent poverty” (about 17% of West Virginians). (See Figure 1.11 for more specific information.) Understanding equity issues provides a means of designing a policy so that it is fair and does not overly burden a given stakeholder group. West Virginia’s unique population, therefore, needs to be taken into consideration when developing CDR policies, particularly given its coal heritage.

Box 1.4. Federal Government Definitions of Equity and Underserved Communities

“The term ‘equity’ means the consistent and systematic fair, just, and impartial treatment of all individuals, including individuals who belong to underserved communities that have been denied such treatment, such as Black, Latino, and Indigenous and Native American persons, Asian Americans and Pacific Islanders and other persons of color; members of religious minorities; lesbian, gay, bisexual, transgender, and queer (LGBTQ+) persons; persons with disabilities; persons who live in rural areas; and persons otherwise adversely affected by persistent poverty or inequality.”

“The term ‘underserved communities’ refers to populations sharing a particular characteristic, as well as geographic communities, that have been systematically denied a full opportunity to participate in aspects of economic, social, and civic life, as exemplified by the list in the preceding definition of “equity.”

Source: White House, 2021

Does West Virginia Need the Potential Revenue from CDR Investments?

In some ways, the West Virginia economy is doing well. As of September 2022, the unemployment rate is 4.0 percent (31,500 state residents); the national unemployment rate is 3.5 percent. Note, however, that unemployment rates do not include those who are underemployed or who have decided to no longer pursue work. This may be a factor in West Virginia’s 16.8% poverty rate as of 2021, which is one of the highest rates in the nation.

West Virginia’s population is unique in a number of ways, as reflected in Figure 1.12. Its population is older than the national average, with only 21% of its population having a bachelor’s degree or higher (11% lower than the national average). Household incomes are more than $15,000 below the national average, and the labor participation rate is almost 10% below the national average. As illustrated in Figure 1.14, most of West Virginia is considered to be a disadvantaged community by the White House Council on Environmental Quality (CEQ).

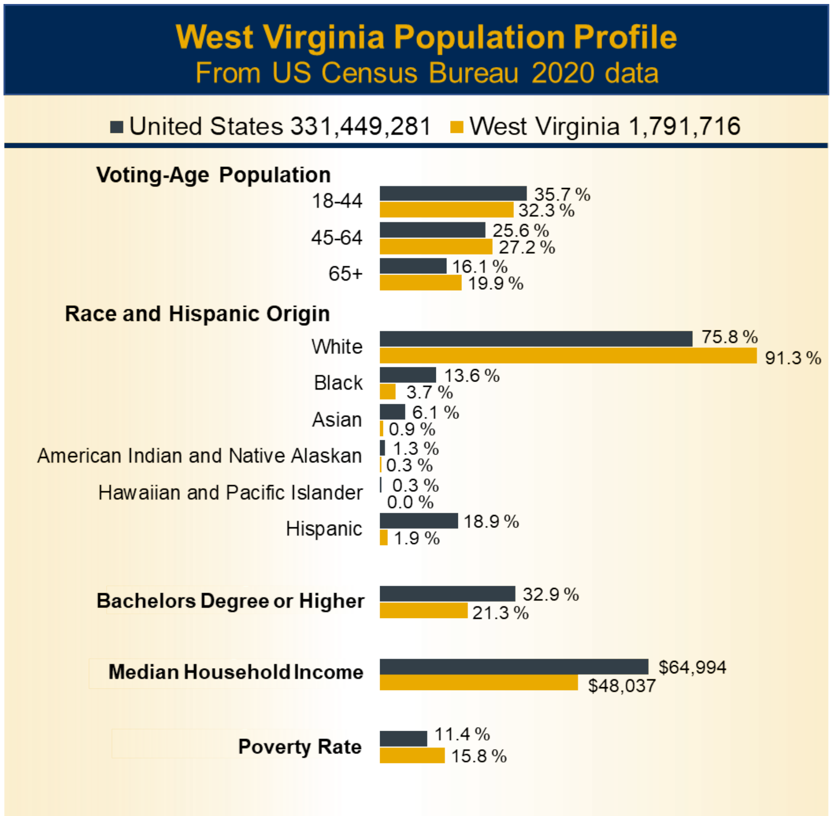


Figure 1.12. West Virginia Population Profile (adapted from the U.S. Census Bureau)

Although many might think that most jobs in West Virginia are in goods production (e.g., manufacturing, natural resources, and mining), the reality is that most private-sector jobs in West Virginia are in the service sector (Figure 1.13).

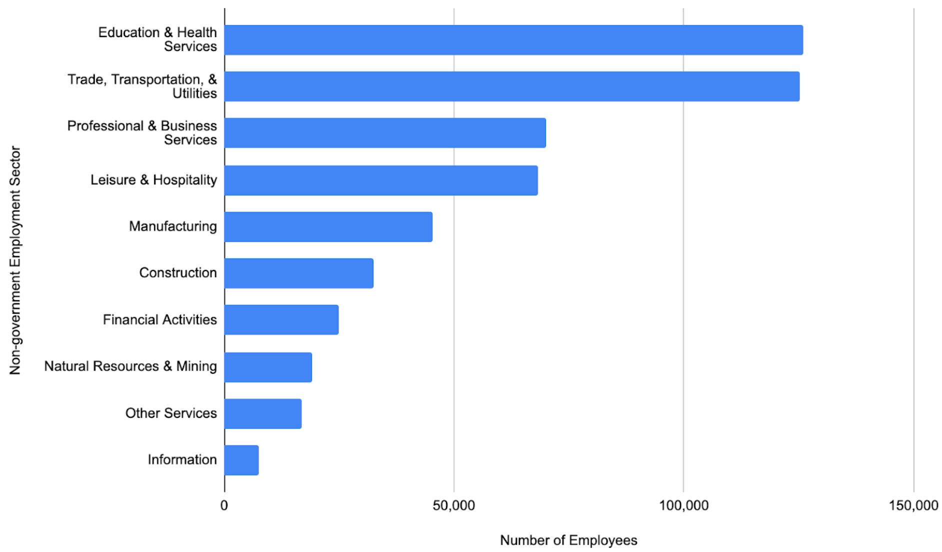


Figure 1.13. Private West Virginia Employment, by Sector, 2021 (Fourth Quarter) (West Virginia University, 2022; data source: WorkForce WV)

Yet, there are challenges as well:

- West Virginia has the second-lowest labor participation rate in the nation (around 46%). Unlike the official unemployment rate, this rate accounts for those who are not in or who have left the labor force. It is also important to note that unemployment rates do not include those who are underemployed.
- Unemployment rates throughout the state are unevenly distributed (Figure 1.14), with rates typically higher in former coal communities and southern counties.
- The "outmigration rate"—that is, the number of working-age West Virginians leaving for other states—has been the highest in the nation over the past decade. In fact, this rate was sufficiently high in the 2020 census that West Virginia lost a congressional seat.

Box 1.5 provides an overview of the challenges West Virginia faces for its future economic growth. Should West Virginia's population or economic development increase (through investments in DAC, for example), however, then the related development could impact the amount of natural carbon removal options available that utilize forests, agriculture, and wetlands.

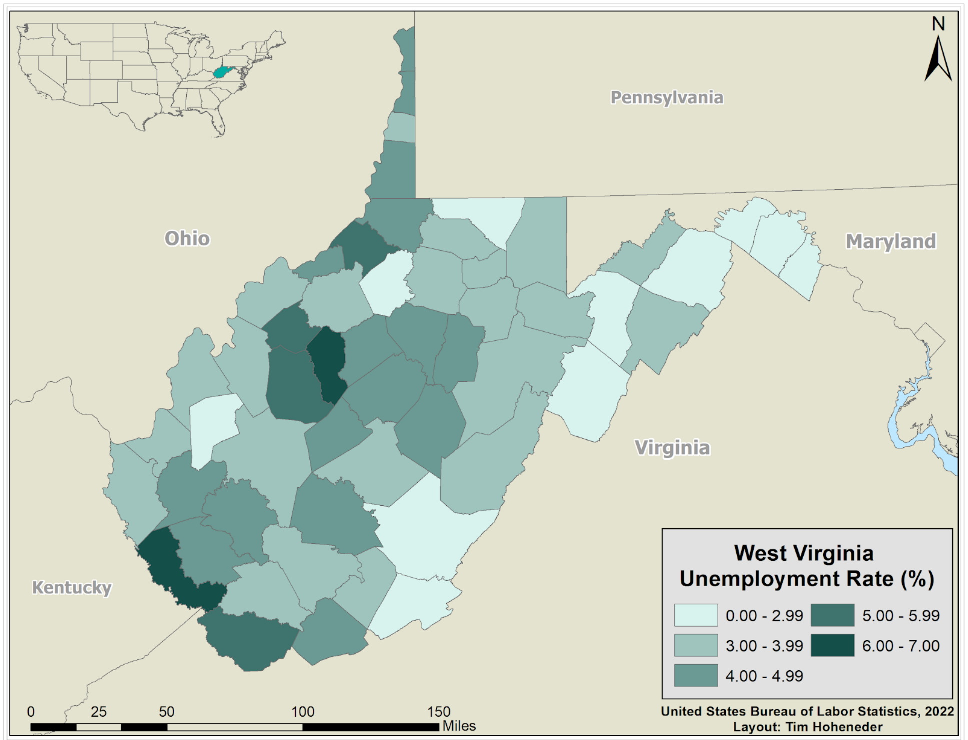


Figure 1.14. Unemployment Rates, by County, West Virginia, November 2021 (U.S. Bureau of Labor Statistics, 2022)

Box 1.5. Challenges to West Virginia's Economic Growth

"The Mountain State's underlying demographics remain a major limiting factor to growth moving forward. Consider the following:

- West Virginia's population has declined by nearly 65,000 since 2012. We project a slower rate of population losses over the next couple of years that will pick back up over the longer term as the state's economy lags broader regional averages.
- A positive shock to encourage in-migration is essential to lessen the severity of natural population[a] decline.
- The state has one of the nation's oldest populations and will see its age distribution continue to skew toward older age groups in coming years.
- Economic development strategies should focus on ways to improve health outcomes, lower drug abuse, and advance educational and vocational training opportunities in the state to make West Virginia's workforce more attractive to potential businesses.

"Economic performance is expected to remain extremely variable across West Virginia's counties. Consider the following:

- Nearly a dozen counties are expected to either lose jobs or record growth that is less than one-half that of the statewide average. The highest rates of job growth tend to be in the northern half of the state.
- While the state overall is expected to lose population in coming years, around a dozen counties are expected to add residents during the outlook period. Population gains will be heavily concentrated in North-Central West Virginia and the Eastern Panhandle.
- Policymakers should be keenly aware of significant economic differences across West Virginia and ensure that economic development strategies consider each region's specific strengths and weaknesses."

[a]Natural population decline refers to the fact that deaths outnumber births in our state (and this has been the case for several years now). There are two components of population change: natural change (births minus deaths) and net migration. The point being made here is that we have natural population decline and there is really nothing we can do about that in the short run. So we need a positive shock to encourage in-migration and reduce out-migration so that we can turn our population numbers in the positive direction.

Source: West Virginia Economic Outlook 2021-2025, West Virginia University, Bureau of Business and Economic Research

Policy Activities Focused on Disadvantaged Communities

In response to the challenges faced by disadvantaged communities, particularly coal communities and communities of color nationwide, President Biden signed Executive Order 14008 in January 2021, establishing an Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization, chaired by National Energy Technology Laboratory Director and former WVU faculty member Dr. Brian Anderson. Disadvantaged communities are located throughout West Virginia (see Figure 1.15).

Coal communities may or may not be disadvantaged communities. The working group established by Executive Order 14008 has identified coal communities that are particularly challenged, and the administration has developed a number of programs to help those communities. Overall, five of the top 25 regions of the U.S. with high concentrations of direct coal sector jobs are in West Virginia. Almost all West Virginia counties have ties to coal, but the counties with the highest concentrations of coal sector jobs are in southern West Virginia, as shown in Table 1.1.

Table 1.1. West Virginia Counties with High Concentrations of Direct Coal Sector Jobs (Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization, 2021)

Areas With High Concentrations of Direct Coal Sector Jobs,	Bureau of Labor Statistics Area	County

Ranked by Number of Jobs		
1	Southern West Virginia non-metropolitan area	Greenbrier Mingo Logan Summers McDowell Monroe Mercer Webster Nicholas Wyoming Pocahontas
3	Wheeling, West Virginia-Ohio	Belmont Marshall Ohio
11	Northern West Virginia non-metropolitan area	Barbour Morgan Braxton Pendleton Calhoun Pleasants Doddridge Randolph Gilmer Ritchie Grant Roane Hardy Taylor Harrison Tucker Jackson Tyler Lewis Upshur Marion Wetzel Mason
23	Beckley, West Virginia	Fayette Raleigh
24	Charleston, West Virginia	Boone Clay Kanawha

Although communities of color do not represent a large percentage of the West Virginia population compared to the national average (Figure 1.16), those communities have been uniquely vulnerable to environmental challenges in the past.

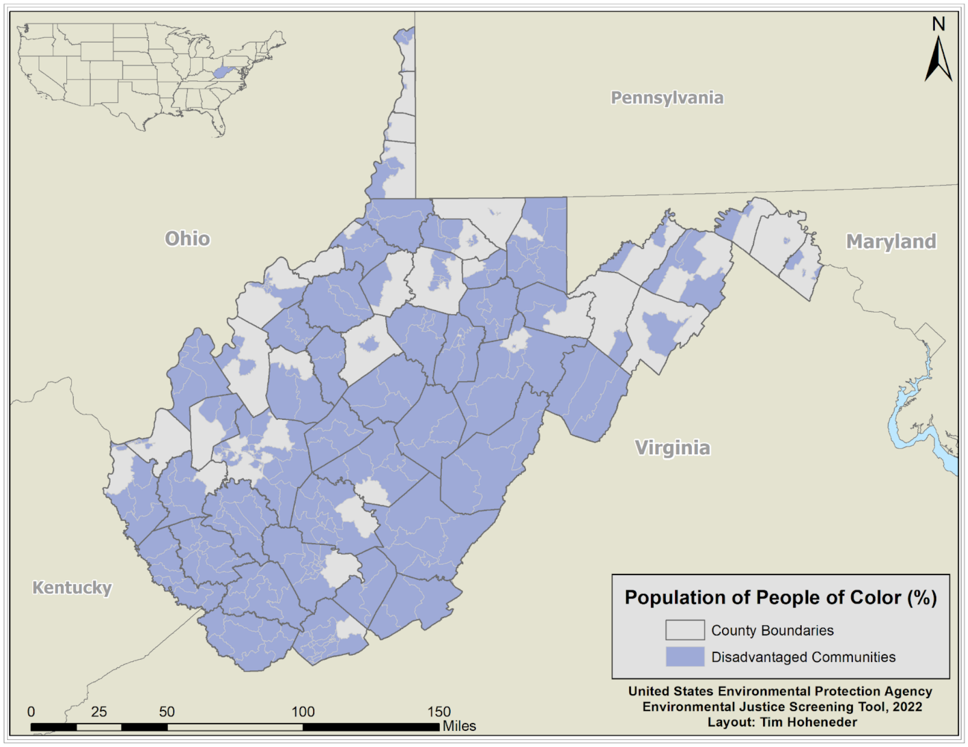


Figure 1.15. Geographic Location of West Virginia Disadvantaged Communities (West Virginia University, 2022; based on data from White House Council on Environmental Quality (CEQ) Climate and Economic Justice Screening Tool, version 1.0, 2022) *The CEQ states that "Communities identified as disadvantaged by the tool are those that are marginalized, underserved, and overburdened by pollution. These communities are at or above the combined thresholds in one or more of eight categories of criteria." Note that this tool does not include race in its definition. Geographic boundaries within West Virginia represent census tracts.*

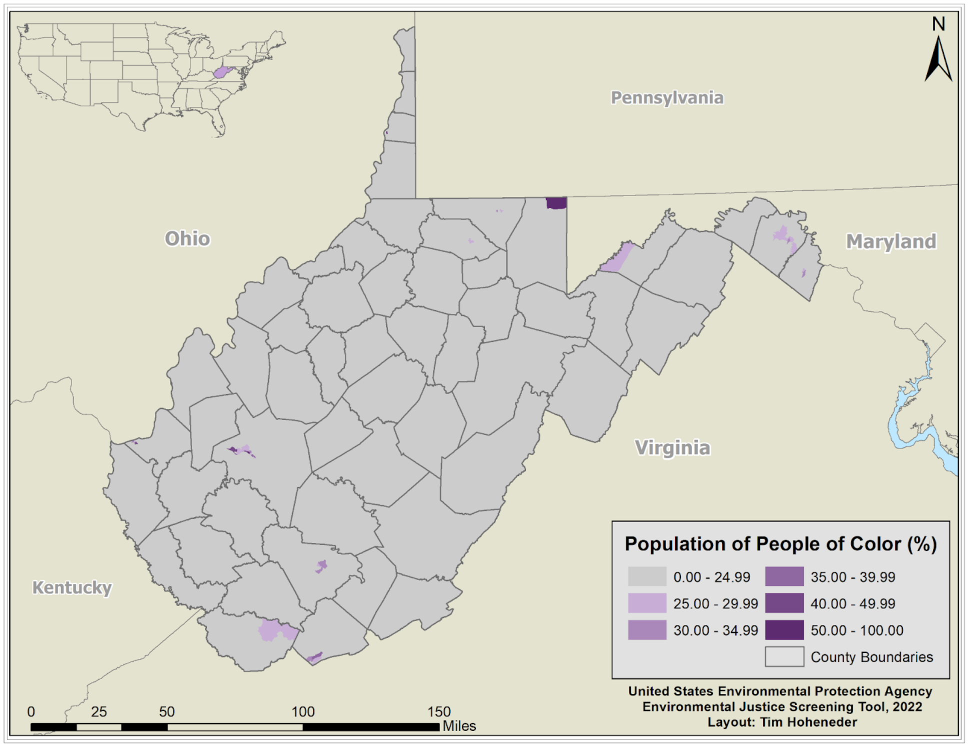


Figure 1.16. Geographic Location of West Virginia Communities of Color (West Virginia University, 2022; based on data from the based on data from White House Council on Environmental Quality (CEQ) Climate and Economic Justice Screening Tool, version 1.0, 2022)

To the extent possible, it is important to locate and develop CDR activities so they can economically benefit disadvantaged communities. In considering CDR options, this analysis will look at opportunities that support this goal.

For example, DAC activities can be located anywhere there is sufficient land and where carbon storage options are available. Ideally, however, they would be located in southern West Virginia to help revitalize the workforce in these communities by supporting existing workers as well as bringing new workers to the region. As discussed in greater detail below, such actions should be considered in partnership with these communities. If a community agrees to move forward, they should do so through community-benefit agreements.

Still, DAC poses a geographical challenge, as the captured CO_2 needs to be stored or converted into products. For instance, the location of West Virginia's chemical industry in the northern part of the state poses an economic challenge if the captured CO_2 is in the southern part of the state and needs to be transported.

General Equity Guidelines and Principles for CDR Activities

On February 15, 2022, the White House Council on Environmental Quality (CEQ) issued Carbon Capture, Utilization, and Sequestration (CCUS) guidelines, which address “technologies that remove carbon pollution from the ambient air or from point sources like smokestacks, and permanently store the carbon.” The guidelines state that actions taken by federal agencies should include

- evaluating the impacts of proposed CCUS actions on potential host communities early in the planning process
- providing information about the effects, costs, and benefits of CCUS in advance of Tribal consultation and stakeholder engagement
- consulting Tribal Nations on potential CCUS projects in a manner that strengthens Nation-to-Nation relationships
- avoiding the imposition of additional burdens on overburdened and underserved communities, including by evaluating direct, indirect, and cumulative effects and identifying and implementing appropriate mitigation and avoidance measures
- providing transparency and accountability to communities with respect to applicable mitigation measures designed to reduce environmental effects

Additional proposed key principles are that

- stakeholders, specifically frontline community members, participate in the decision-making process, not just policymakers and experts
- benefits be allocated fairly, with benefits being automatic for some community members and earned for others
- harms minimally impact community members previously disadvantaged, and preferably not at all
- transformations help the most disadvantaged in ways identified by the frontline community members

Equity Challenges and Principles Specific to West Virginia

In the case of West Virginia, key equity challenges include

- the social and economic disadvantage of certain demographic groups, including those residing in rural and coal communities as well as people of color
- wealth generated in West Virginia from natural resources historically leaving the state because companies and land utilizing those resources are disproportionately owned by non-West Virginians or those who have already benefited from the land via inheritance or through wealth

- owners of surface rights (e.g., homeowners), in most circumstances, being unable to benefit from economic activities below the land they own because they do not own the subsurface rights

When these concepts are applied to CDR in West Virginia, the following equity principles arise:

- Economic opportunities related to CDR should benefit the entire community—ensuring employment and wealth-generating opportunities for all community members, not just those who own land.
- The communities themselves, not just policymakers, should determine whether CDR activities will occur in or near their hometown based on their assessment of economic opportunities and potential harm.
    - In particular, these conversations should incorporate the concerns of marginalized people who are typically not included in these conversations, providing them with opportunities to participate directly in the discussions.
    - Furthermore, engagement of local civic and community-based organizations is critical to engaging enough voices and perspectives that there are broader, more genuine conversations than are likely to occur if only local government entities are involved.
- Should the CDR activity take place, the community members should also help determine how the related economic benefits will be distributed and the best way to monitor activities to ensure that any harm that occurs is minimal. One mechanism for taking these actions is Community Benefit Agreements (Box 1.6).
- In determining the geographic location of CDR activities, policymakers and funding organizations should take into consideration the need for economic development in West Virginia's most disadvantaged communities while at the same time ensuring that any harm that comes to these communities is minimal.

Box 1.6. What is a Community Benefit Agreement?

A Community Benefit Agreement (CBA) "is an agreement signed by community benefit groups and a developer, identifying the community benefits a developer agrees to deliver, in return for community support of the project. Community benefit groups are coalitions comprised of neighborhood associations, faith-based organizations, unions, environmental groups and other stakeholders. They represent the interests of residents who will be impacted by proposed developments. CBAs can ensure that measurable, local benefits will be given to a community. They are enforceable, legally-binding contracts for all parties that stipulate community benefits and are the direct result of substantial community input."

The DOE offers the following strategies:

"Developers

- Identify stakeholders and build public trust. Stakeholders should represent a diverse group of community-based organizations and individuals.

- Engage community representatives, as well as coalitions, and communicate project benefits with open dialogue/transparency.

- Ensure stakeholder representatives are part of the project development team early in the process and align project goals and schedules with their understanding.
- Initiate project briefings with key state and local government officials.
- Train company project representatives about community outreach and CBAs.
- Educate stakeholders about the technical aspects of the development.

"Communities

- Research development proposals in your region and identify any that have the potential to bring important benefits or significant impacts to the neighborhood(s) where they will be located.
- Organize a broad-based coalition of community interests and recruit stakeholder organizations.
- In order to maximize turnout, hold public meetings with assistance from identified leaders. Utilize multiple communication mechanisms to reach affected populations.
- Actively engage the developer(s) with sustainable community objectives, via open dialogue and transparency.

"State and Local Governments

- Inform community coalitions of proposed developments.
- Encourage developers to enter good-faith negotiations with responsible coalitions.
- Inform developers of the benefits they can achieve through CBAs.
- Respect the negotiating process and honor community coalition agreements.
- Fold CBAs into public-private partnership (PPP) agreements—when and where appropriate—for added enforcement."

Source: Guide to Advancing Opportunities for Community Benefits through Energy Project Development, Department of Energy, 2017

What Ecological, Conservation, and Environmental Opportunities and Challenges Should be Considered When Assessing CDR Activities?

Although CDR activities can be beneficial to the environment, they can pose challenges as well. We have found, for example, that reforestation efforts need to be conducted very carefully so they do not impact the overall ecology of the region, and West Virginia's Department of Natural Resources has a useful tool to help identify native plants, which can in turn support local species. Even more important than planting new forests is protecting existing forests, particularly those on public lands, and increasing their survival rate.

In this policymaker guide, we focus on three ecosystem aspects in our assessment of CDR activities in West Virginia:

- Ecological: living organisms and their surroundings
- Conservation: planned management of a natural resource to prevent exploitation, destruction, or neglect
- Environment: air, water, and waste pollution

Table 1.2. Potential Environmental Challenges in Implementing CDR

CDR Option	Potential Environmental Challenges
Forestry	• Lack of consideration for local conditions in reforestation management practices can result in poor outcomes and decreased biodiversity, especially on previously mined lands. • Afforestation may require fertilizers that could make their way into local water systems. • Managing forests primarily for carbon removal can compete with other conservation efforts, resulting in fewer old growth forests, or reduced habitat for native plants and wildlife.
Agriculture	• Additions of fertilizer materials, including manure, can contaminate local water systems. • Conversion of land to agriculture typically reduces local biodiversity and wildlife habitat, negatively impacts stream quality, and can lead to increased invasive species.
Wetlands	• If not properly restored or created, wetland restoration failures can lead to more erosion, invasive species colonization, over-abundance of predators, and other ecological challenges. • Depending on the hydrology, or movement of water, in a restored wetland, they could release methane (CH_4), which is a potent greenhouse gas.
Bioenergy with	• Potential limiting of freshwater and decreased groundwater availability without sustainable water management practices.

Carbon Storage	• Monoculture of crops results in reduced biodiversity and resilience.
Direct Air Capture	• Construction of storage sites may result in net gains to CO_2, and can negatively impact local air and water quality.
Carbon Storage	• Underground storage may result in changes to groundwater chemistry, potentially impacting drinking water systems drawn from local wells. • Potential leakage from geologic reservoirs poses concerns for local communities.

Policymaker Guide Organization

In the following sections, we will analyze each of the CDR options that are possible in West Virginia in response to the committee's charge. In Section 2, we discuss natural carbon sequestration including forests, agriculture, and inland wetlands. In Section 3, we discuss technologically enhanced natural methods focusing on bioenergy with carbon capture and sequestration (BECCS). In Section 4, we discuss technological options with a focus on direct air capture (DAC). In Section 5, we analyze the carbon sequestration, storage, and utilization needed for BECCS and DAC activities in West Virginia. Finally, in Section 6, we bring together our findings and develop policy options and recommendations.

2: Natural CDR Processes: Forests, Agricultural Lands, Wetlands

Natural processes have the potential to capture CO_2 in West Virginia, particularly through forest and land management practices. These opportunities have the advantage that they can be enacted immediately because the “infrastructure” required up front (forests, agricultural lands, and wetlands) is already in place. Much of the land in West Virginia, including forests, pastures, grassland, and cropland, is in suboptimal condition and is not at full productivity. In addition, wetlands are in decline due to development activities. To maximize natural CDR at the state level, the protection of existing forests, wetlands, grasslands, and pastures is as (if not more) important as the management and cultural practices that expand the carbon capture potential of these areas.

The permanence of any increased carbon pool in forests, agricultural lands, or wetlands resulting from improved management depends on many factors, however. Examples include the need for **long-term** management practices (100+ years) and recognition that the occurrence of natural disasters may lead to the reversal of carbon sequestration. Therefore, the effectiveness of natural CDR practices for mitigating climate change is still under debate (here are some of the pros and cons) and depends on the specific long-term practices used to manage the lands in question. Nonetheless, management practices intended to increase carbon sequestration have many other co-benefits, such as enhanced resilience to extreme events.

The current analysis excludes timberland owned by corporations. Along with timbering, these companies already participate in some carbon sequestration activities as part of their business model. We believe that they are in the best position to make decisions regarding the use of their land. (This section does, however, discuss the topic of timber utilization.)

Instead, this analysis focuses on family forestlands and public lands owned by the federal and state governments. As shown in Figure 2.1, forest management from these two sectors has the greatest potential for carbon sequestration (1.05-5.87 MMT CO_2e/year), followed by agricultural management (0-2.6), abandoned mine land restoration (0.03-0.28), and wetland restoration (0.03- 0.06). Detailed information on how these estimates were developed can be found in Appendix D.

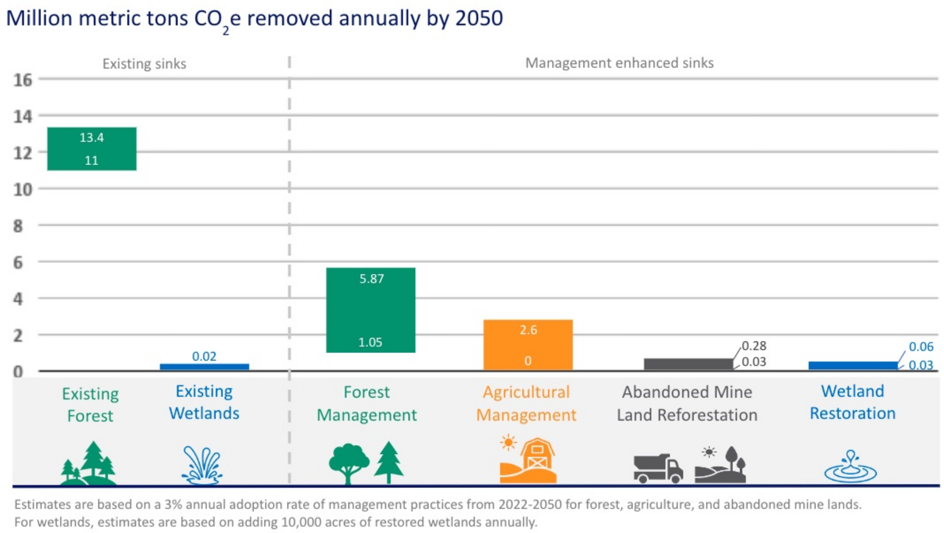


Figure 2.1. West Virginia's Natural Carbon Sequestration Potential (West Virginia University, 2022)

Table 2.1 provides an overview of the potential economic impact if West Virginia policymakers were to encourage these efforts. The annual total economic impact is estimated to be $18.2-81.3 million in economic output and 200-892 jobs per year. Detailed information on this analysis can be found in Appendix J.

Table 2.1. Annual Economic Impact of Natural Carbon Sequestration Efforts in West Virginia (West Virginia University, 2022)

	Direct Impact	**Indirect & Induced Impact**	**Total Economic Impact**
Output ($, millions)	12.2 – 54.6	6.0 – 26.7	18.2 – 81.3
Employment (jobs)	126 – 561	74 – 331	200 – 892
Labor Income ($, millions)	7.8 – 34.8	2.7 – 12.0	10.5 – 46.9
Total Taxes ($, millions)	0.7 – 3.2	0.3 – 1.1	1.0 – 4.3

Note: Tax Revenue impact includes sales, personal income, property, and corporation net income taxes.

Forest Management Practices

West Virginia has the second highest above-ground live forest per acre in the lower 48 of the United States. Improved forest management (Figure 2.2) can increase the amount of CO_2 that is stored in these forests. A large majority of West Virginia timberland is harvested using diameter-limited cutting to maximize economic gains but not carbon sequestration. This method may increase revenue in the first harvest, but over time can lead to a loss of carbon stored, lower-value timber stocking, and altered wildlife habitat. Thus, improved forest management (Figure 2.2) can allow landowners to both earn revenue for carbon sequestration and improve the overall wood products value of their land. To promote forest management for carbon storage, the Inflation Reduction Act of 2022 includes a $5 billion investment in forest management, planning, and reforestation on federal and non-federal lands.

Figure 2.2. Improved Forest Management (IFM) (Griscom and Cortez, 2013) *IFM includes better harvesting in areas where logging occurs, the protection or setting aside of some areas from logging, and silvicultural practices to improve growth.*

Any additional carbon removed from the atmosphere and stored in forests due to active forest management can potentially be sold in the carbon market as carbon offsets/credits. Most of the current forest carbon offset programs consider reforestation, improved forest management, and avoided conversion as acceptable management activities that increase forest carbon stocks and produce carbon credits. In the California Cap-and-Trade program, for example, improved forest management is the most commonly used protocol to generate carbon offsets. While standards vary from program to program, carbon offsets are required to be **additional** (see Box 1.2), **permanent** (e.g., 100 years), and without **leakage.** Leakage refers to carbon emissions reductions from one place shifting to another place. For example, if a forest harvest is delayed to qualify for carbon offsets, but another forest nearby or faraway is cut instead, this would be considered leakage and not a true offsetting of carbon emissions.

While improved forest management typically includes some form of wood harvesting, some stakeholders have expressed concerns about how managing forests for optimal carbon sequestration might impact the forest products industry or other environmental or societal goals (e.g., flood mitigation, invasive species control). Under some circumstances, managing forests for carbon sequestration requires reduced timber harvests or longer harvest cycles, so incentivizing forest carbon offsets may indirectly impact the forest products industry or drive up lumber costs by reducing the supply of timber. Under other circumstances, net CDR may be maintained or increased if timber harvests are performed in a way that allows young forest regeneration or maintains uneven age class, efficiently stores the carbon from harvested trees in long-lived wood products, or prevents other disturbances to the landscape (e.g., by insects or wildfire). Some forest carbon offset programs, like the California Cap-and-Trade program, do consider carbon stored in wood products as part of the carbon accounting for carbon offsets.

There is a debate around whether young forests sequester carbon more rapidly than old forests, and the solution likely lies in the time-scale, spatial area, and specific management practices under question. In temperate forests like those in West Virginia, recently harvested (young) forests are likely a source of carbon emissions–even though the trees are growing fast–because of the decomposition of wood residue and soil carbon following harvest. However, given enough time and proper management, harvested forests may return to their previous carbon stocks and continue to sequester carbon in wood and soil even as mature and old-growth forests (Figure 2.3).

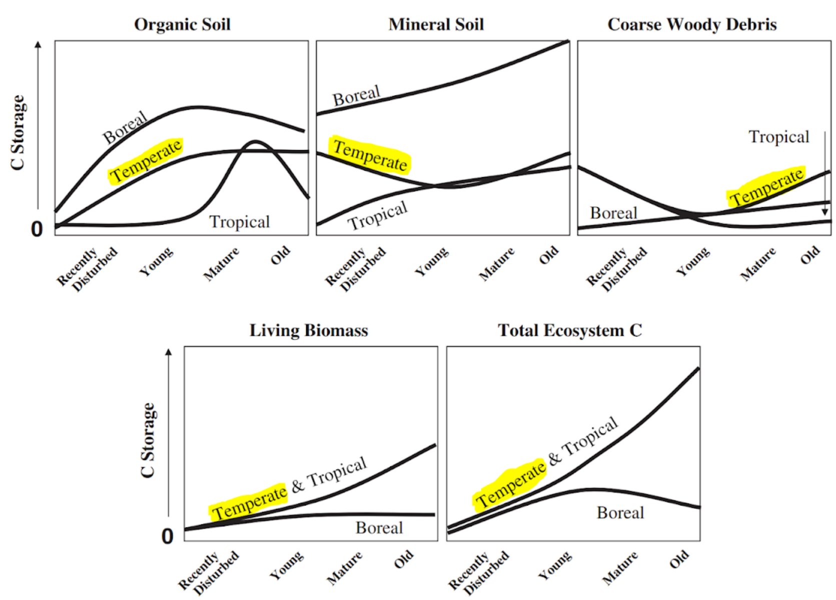


Figure 2.3. Change in Carbon (C) Storage in Forest Soil and Trees (Living Biomass) Following Disturbance and Through Old-Growth Forest Age (Birdsey et al., 2006; adapted from Pregitzer and Euskerchen, 2004) *Temperate forest trends are highlighted in yellow, representative of most West Virginia forests, and continue to increase carbon storage through old-growth status.*

Overall, the specific details and criteria of when to harvest and when to allow the trees to continue to grow for optimal carbon storage are complex, depending on many different environmental, economic, and social factors (e.g., site characteristics of the landscape and environment, wood product prices and demand, landowner goals). No scientific consensus currently exists on how best to optimize net carbon storage through forest management that considers the life cycle of carbon in harvested products.

When discussing these CDR efforts in West Virginia, it's important to consider who owns the land (Figure 2.4). To date, about 5% of West Virginia's land (approximately 700,000 acres) is already involved in active CDR activities, the average size of West Virginia's carbon projects is 59,000 acres, and there are no projects below 5,000 acres. Most of these larger tracts are corporate-owned lands, which account for all of the 28 million credits issued from 2015-2020 through the California Cap-and-Trade market. Although land holdings of any size can make a contribution to CO_2 emission removal, few family-owned forestlands (which, though smaller on average, make up about half of West Virginia's total forestland) are currently involved in CDR activities.

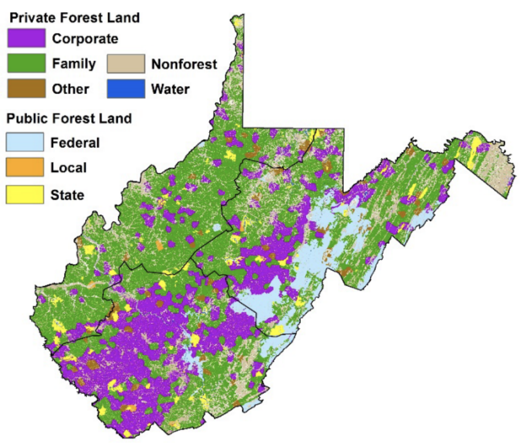


Figure 2.4. West Virginia Forestland, by Owner (U.S. Department of Agriculture, 2016)

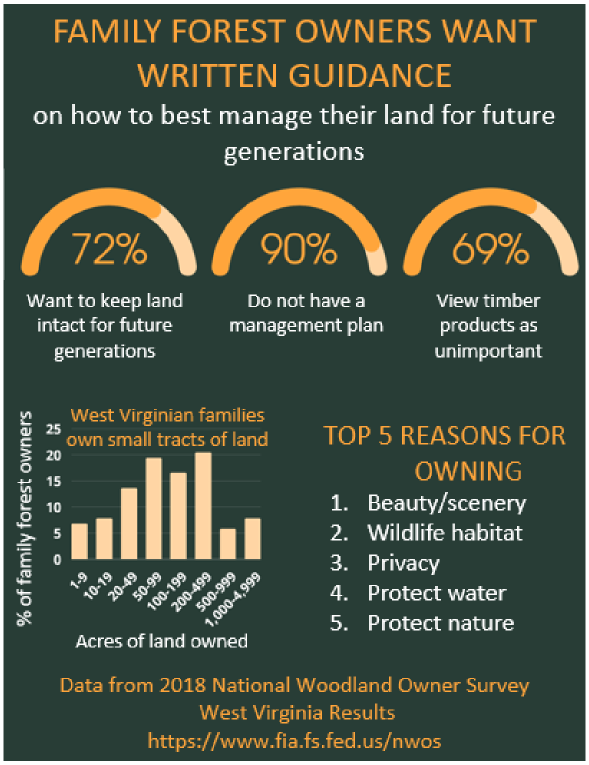


Figure 2.5. Family Forest Owner Preferences (West Virginia University, 2022; based on data from the U.S. Department of Agriculture, 2018)

Family Forest Lands

In this policymaker guide, we focus primarily on family forestlands when the owners of the land are not interested in participating in the forest product industry (Figure 2.5). That is because the forest product industry is already active in carbon sequestration efforts and has sufficient land holdings that qualify for existing carbon credit programs. The same is not always true for family forest lands.

Participation in carbon market programs, however, can help the 10% of West Virginians who own forestland by procuring the funding needed for families to maintain this land, as well as the surrounding rural areas if those landowners decide to participate. Another benefit of these programs is that they bring dollars from outside the state into West Virginia.

Box 2.1. Example of Forest Carbon Program Participation in the Region

Forest carbon programs allow forest landowners to receive payment for taking certain management actions on their land that increases the rate of carbon stored by their forest. Here we provide one of three examples from Penn State Extension of a forest-owning family in Pennsylvania who considered two very different forest carbon programs that are also available to West Virginia forest landowners: the Natural Capital Exchange (NCX) and the Family Forest Carbon Program (FFCP).

A Pennsylvania family, the Wilsons, owns 130 acres of forest, 30 of which was previously harvested to conserve warbler habitat. For the remaining 100 acres, they looked at both the FFCP and NCX programs. "[T]he FFCP payments for the Wilsons would have an average annual net present value of $4.00/acre (3% discount rate). Through NCX, they expected to make $8 an acre on the 100 acres of mature forest for a total of $800 in a year. All NCX contracts are for 1 year at a time and payment levels are renegotiated each year. Assuming they would continue to get $8 per acre for the next 20 years the authors of this paper estimate the NCX payments have an average annual net present value of $2.60/acre (3% discount rate). One key difference between the programs was that the FFCP allowed them to create small gaps in mature forest areas, which the NCX program did not allow that practice. In the end, the Wilsons elected to participate in the FFCP program."

For the three case studies examined by Penn State they found that "[t]he largest obstacles these landowners faced was finding a qualified forester. This is due to both a lack of foresters in Pennsylvania and that few of them are certified to work with forest carbon programs, largely because carbon markets are a new industry…The owners interviewed all recognized that forest carbon does not generate a huge sum of money, but…supplemented their income in ways that helped them meet their own objectives and help contribute to climate change solutions."

"After this article was published, FFCP has updated their policy to allow foresters on their staff to write plans for landowners. This may reduce the barriers of entry to landowners and speed time to enrollment."

Experiences like the Wilsons' and the others portrayed by Penn State may differ from what a West Virginia landowner might experience, but they do identify some key questions landowners should ask and emphasize the importance of comparing programs.

Several challenges, however, lead to the need for possible policy interventions:

- Participation in private carbon programs is challenging for family forest landowners due to resource constraints.
- Carbon credits must represent *additional* and *permanent* carbon sequestration beyond the current rate of carbon sequestration (i.e., if no actions were taken), and this depends on the initial conditions of the forest, requires a skilled forester, and must be monitored long term.
- Federal carbon tax credit programs, as detailed in Internal Revenue Code Section 45Q, do not support natural methods such as forest sequestration.

- Some forest carbon offset agreements require long-term commitment (over 100 years) and restrict land use (Table 2.2).

The first challenge is being addressed through state, private industry, and non-profit programs that provide funding and other resources to landowners to create and start a management plan. Additionally, carbon offset agreements are made more economically advantageous to small landowners in West Virginia's 2020 Statewide Forestry Plan:

> "The use of carbon credits to provide annual returns to the landowner from their forestland investment should be explored and promoted within the state with particular emphasis on gaining access to this opportunity to landowners who own less than 500 acres to enroll in the program. Landowners might be more willing to participate in a carbon credit program if they were given the chance to participate with other landowners in the area in some type of cooperative effort that would promote more of an economy of scale than is typically available for an individual landowner with less than 500 to 1000 acres of forestland available for enrollment."

The second challenge is that forest carbon offsets are produced from *additional* carbon stored by a forest beyond what the forest is already sequestering under its current management (or lack of management). Thus, actions must be taken to increase the rate of carbon stored in the forest over the term of an offset agreement, which may be minimal or challenging on lands that already have a high carbon stock. Some current standards for sustainable forest management, such as those managed by the Sustainable Forestry Initiative and the Forest Stewardship Council, may be especially challenging to further increase carbon sequestration. Thus, forest managers who are already practicing good management methods may not be eligible to be rewarded for their efforts on the carbon market because they are already benefiting from other programs.

The third challenge is that current federal policies and practices do not provide appropriate compensation to these family forestlands nor to forest product companies. For example, Section 45Q provides tax credits for carbon sequestration activities but does not include natural processes or storage in wood products when determining eligibility. In addition, the private options currently available provide low compensation to landowners and often require long commitments for participating in the carbon credit process (Table 2.2).

The Forest-Climate Working Group—a forest sector coalition that focuses on the use of forests and forest products to combat climate change—recommends the implementation of a landowner tax credit for private forest carbon actions:

> "A transferable tax credit could incentivize carbon sequestration in privately-owned forests, with credits provided for increased carbon sequestration. With transferable tax credits, if the value of the tax credit is higher than the taxpayer's tax liability, he/she can sell or transfer the excess credits to any other taxpayer. Making the tax credit transferable creates many more opportunities for financial gain for the landowner, as they are not limited by their own tax liability. While the Federal Tax Code section 45Q incentivizes carbon capture and storage in the energy sector through a tax credit, it does not provide a similar incentive for the forest sector."

They also distinguish between practices that work best for smaller landowners and those more suited to large forest landowners. A practice-based option tends to work better for small landowners, and a performance-based option typically works better for large landowners and encourages innovation. A description of each is below.

- "Practice-based: the tax credit is determined by approved practices that the landowner implements (selected from approved USDA list). We recommend practices be determined on a regional basis.
- Performance-based: the tax credit is determined by measurable carbon sequestration performance above a baseline."

The fourth challenge highlights the importance of access to information by landowners who are considering whether forest carbon offset agreements are right for them. Table 2.2 provides an overview of different forest carbon offset programs that are currently available to West Virginia private landowners and vary in their requirements. For example, several of the programs require acreage beyond that of a family forest, and in some cases landowners may build cooperatives to bring together enough acreage to qualify for these programs. However, similar efforts in the past have sometimes been challenging to implement, as an error by one landowner may adversely impact the others who are part of the cooperative agreement.

Another factor is the duration of the agreement. Some programs require a shorter time commitment (10-20 years) while others require a longer commitment (100 years). The longer-term agreements restrict land use activities and require specific land management protocols to be followed for the duration of the term. While landowners can choose to withdraw, early termination results in repayment of credits and a fine. Most still allow harvesting, though others do not (see the NCX program). These programs are expanding, and conditions are changing as well, so fully understanding the conditions of these programs is important.

Table 2.2. Current Forest Carbon Storage Economic Opportunities for Private Owners of West Virginia Forestland (West Virginia University, 2022; based on data from Forest Carbon Works[1], The Nature Conservancy [2], and American Forest Foundation; NCX[3]; Penn State Extension[4])

Name	Acres required	Pricing	Term agreement duration	Harvest allowed?
California Air Resources Board (CARB) regulatory market	40+	Variable, depends on market $20 per acre per year to $100+ per acre per year[1]	100 years	Yes
Family Forest Carbon Program[2]	30-2,400	Payments depend on property size, forest conditions, management plan; $50-280/acre[2]	10-20 years	Yes
Working Woodlands Program[2]	2,000 +	Variable, depends on carbon credits market	Variable, long-term conservation easements (e.g., 40 years)	Yes

NCX[3] (National capital exchange)	None	Variable, based on landowner bids[3] ~$8/acre (e.g., 2020 PA bid[4])	1 year	No

In addition to the carbon offset programs available to West Virginia landowners, pre-established forest conservation programs also provide financial incentives through cost-sharing, tax incentives, and/or direct payments to landowners who choose to participate. While these programs were not created for the purpose of carbon sequestration in these lands, many of the encouraged management activities produce the co-benefit of enhanced carbon sequestration.

The Forest Climate Working Group has suggested a number of policy options to improve the current system (Box 2.2).

Box 2.2. Forest Climate Working Group Proposed Policy Options

The Forest Climate Working Group, a coalition of private landowners, forest products companies, state foresters and other government agencies, forestry, conservation and wildlife non-profits, carbon finance, and academic researchers, identifies the following policy options:

"A transferable tax credit could incentivize carbon sequestration in privately-owned forests, with credits provided for increased carbon sequestration. With transferable tax credits, if the value of the tax credit is higher than the taxpayer's tax liability, he/she can sell or transfer the excess credits to any other taxpayer. Making the tax credit transferable creates many more opportunities for financial gain for the landowner, as they are not limited by their own tax liability. . .

The practice-based approach can appeal to smaller landowners and is USDA's comfort zone. The performance-based approach works better for large forest owners, offers opportunities at scale, invites innovation, and is USDA's aspiration. If crafted well, a landowner tax incentive for forest carbon sequestration could increase the return on investment to private forest owners for carbon sequestration and catalyze further efforts by private forest owners in being a solution at scale on climate."

State Forest Lands

West Virginia's 2020 Statewide Forestry Plan also recognizes the importance of managing state-owned forest lands to sequester carbon. One of the mandates for the management of State Forests is to demonstrate sound, scientific, multiple-use management. To that end, managing state forests for maximum carbon sequestration as a forest resource is important. Yet, meeting the additionality criteria for carbon credit programs can be challenging because these forests may already be sequestering carbon at a high rate, and additionality only occurs when the rate of sequestration increases.

The Statewide Forestry Plan plan notes that carbon offset projects will be developed over the next 5 years. One question not addressed in the plan is the potential for economic benefits for participation in carbon credit programs that could fund these projects beyond what state funds might allow.

Monongahela National Forest

West Virginia's Monongahela National Forest, established in 1920, is one of the most ecologically diverse areas in the United States. It is also a working forest providing timber, water, grazing, minerals, and recreational opportunities (Figure 2.6). In the past, some areas of the national forest were mined, and that land and related wetlands (particularly the Lambert Run Watershed) are in the process of being restored. The Monongahela and other national forests could play an important role in the nation's response to climate change, but such contributions would require some financial support. The good news is that these funds are available through recent federal funding in the Inflation Reduction Act and Infrastructure Investment and Jobs Act.

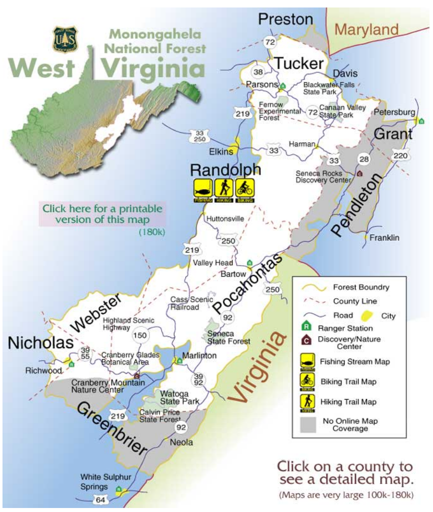


Figure 2.6. Map of Monongahela National Forest (U.S. Forest Service, 2022)

In 1980, Congress established the Reforestation Trust Fund (RTF), which is supported by national forest timber sales. According to the Forest Climate Working Group, this funding is on the order of $100 million annually and can be as high as $178 million. Yet, the working group says, the legislation limits the USFS to only $30 million. The proposal to lift this cap was approved as part of the Infrastructure Investment and Jobs Act, signed into law in November 2021. Additionally, $2.15 billion was invested in managing U.S. National Forests in the Inflation Reduction Act of 2022. Implementation of these laws is still being discussed, but potentially significant federal funding, as well as matching funds, may be available for reforestation efforts and improved forest management for carbon sequestration in the Monongahela and other national forests. In addition, the Biden administration announced an executive order to protect old-growth forests, which may have unknown impacts on the management of the Monongahela National Forest.

Abandoned Mine Lands

West Virginia has approximately 200,000 acres of unreclaimed or under-reclaimed Abandoned Mine Lands (AML). As shown in Figure 2.7, West Virginia has more outstanding mine land reclamation than any other state. One study found that each forested acre of AML could store 6.2 tons/acre annually (5.6 metric tons/year; 13.9 Mg/ha) of CO_2. The federal Abandoned Mine Reclamation Fund provides financial resources that could be used for these reforestation efforts, which was recently prioritized with an additional $11.3 billion emergency appropriation for AML reclamation, nationally, in the Infrastructure Investment and Jobs Act. In West Virginia, these resources are administered by the WV Department of Environmental Protection (WVDEP) to enhance economic development. This program has administered $130 million since 2016. Abandoned mine land reforestation has potential co-benefits given the societal goal to restore these lands and to provide economic development opportunities for former coal mine communities. Many abandoned mine site in West Virginia have unemployment rates greater than 5% (Figure 2.8). One estimate indicates that the recent federal investment in AML could result in approximately 1,730 jobs and $4.3 billion in economic output over 15 years.

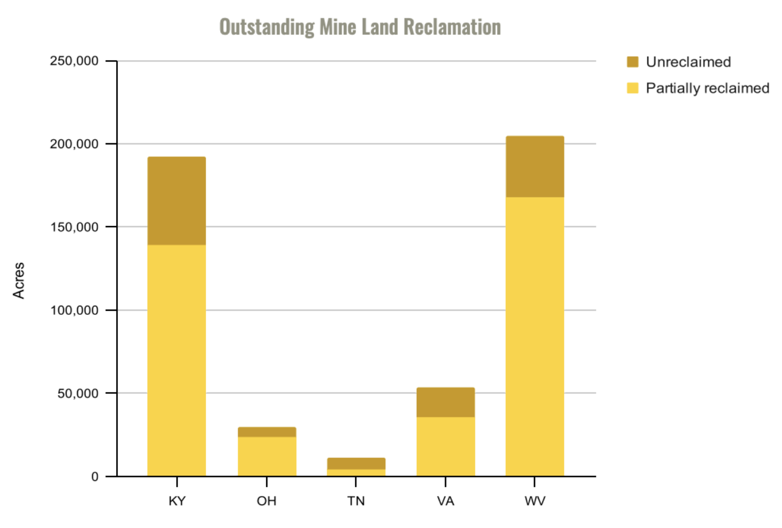


Figure 2.7. Outstanding Mine Reclamation in Appalachia (Appalachian Voices, Coalfield Development Corporation, Rural Action, and Downstream Strategies, 2020)

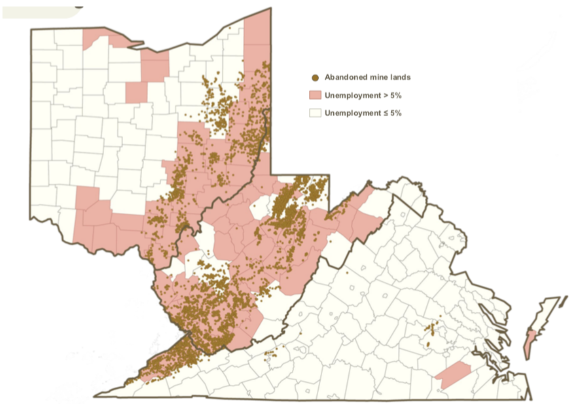


Figure 2.8. Location of Abandoned Mine Lands in West Virginia and Unemployment Patterns (Downstream Strategies, Reclaiming Appalachia Coalition, 2021)

Abandoned mine lands, compared to the rest of the state (which is heavily forested), offer the most significant potential benefits for reforestation efforts.

Box 2.3. Ten Golden Rules For Reforestation To Optimize Carbon Sequestration, Biodiversity Recovery And Livelihood Benefits

"Urgent solutions to global climate change are needed. Ambitious tree-planting initiatives, many already underway, aim to sequester enormous quantities of carbon to partly compensate for anthropogenic CO_2 emissions, which are a major cause of rising global temperatures. However, tree planting that is poorly planned and executed could actually increase CO_2 emissions and have long-term, deleterious impacts on biodiversity, landscapes and livelihoods. Here, we highlight the main environmental risks of large-scale tree planting and propose 10 golden rules, based on some of the most recent ecological research, to implement forest ecosystem restoration that maximizes rates of both carbon sequestration and biodiversity recovery while improving livelihoods. These are as follows:

(1) Protect existing forest first;

(2) Work together (involving all stakeholders);

(3) Aim to maximize biodiversity recovery to meet multiple goals;

(4) Select appropriate areas for restoration;

(5) Use natural regeneration wherever possible;

(6) Select species to maximize biodiversity;

(7) Use resilient plant material (with appropriate genetic variability and provenance);

(8) Plan ahead for infrastructure, capacity and seed supply;

(9) Learn by doing (using an adaptive management approach); and

(10) Make it pay (ensuring the economic sustainability of the project).

"We focus on the design of long-term strategies to tackle the climate and biodiversity crises and support livelihood needs. We emphasize the role of local communities as sources of indigenous knowledge, and the benefits they could derive from successful reforestation that restores ecosystem functioning and delivers a diverse range of forest products and services. While there is no simple and universal recipe for forest restoration, it is crucial to build upon the currently growing public and private interest in this topic, to ensure interventions provide effective, long-term carbon sinks and maximize benefits for biodiversity and people."

Source: Di Sacco et al., 2021

Analysis of Forest Management Practices

Table 2.3 provides an overview of the opportunities and challenges of potential actions with regard to science and technology, economic prosperity, environment and conservation impact, and disadvantaged communities impact.

Table 2.3. Opportunities and Challenges of Forestry to Reduce Carbon Dioxide in West Virginia (West Virginia University, 2022)

	Opportunities	**Challenges**
Science and technology	• The "infrastructure" (i.e., forests) for CO_2 capture is already in place, and the process is well established (which is not the case for technical options).	• Some analysts indicate that forest-based CDR estimates are systematically over-credited in terms of how much CO_2 is reduced quickly and permanently. • There is a need to develop methodologies for net carbon accounting of sequestered carbon among nonprofit, federal, and state agencies to maximize eligibility of forest carbon to be sold as offsets. • In developing carbon accounting standards, carbon retained in manufactured wood products for the entire life cycle should be included.
Economic prosperity	• Small family forest owners' primary concern is preserving lands for family, as opposed to	• The cost of improved forest management and verification of carbon storage may exclude family forests from

	gaining economic benefits from timbering the land. CDR activities provide an alternative method of making income from their land while at the same time maintaining it for future generations. ● Sustainable harvesting and management can improve the overall wood products value of tree stock, provide access to premium wood product markets, and provide significant tax incentives. ● Programs that allow harvesting support the wood products industry and jobs.	some markets. ● Restrictions on land use from carbon offset agreements can create potential loss of liquidity of assets or other development opportunities. ● There is some degree of financial risk in entering into long-term agreements because future prices of carbon are unpredictable. ● AML may offer greater economic benefits through solar installation or other development rather than through reforestation. ● Some past cooperative forest carbon agreements that aggregate land holdings have failed due to the error of one landowner, thereby disqualifying all other landowners in the cooperative.
Environmental and conservation impact	● Sustainable forest management, reforestation, and afforestation can improve soil quality, reduce erosion, maintain valuable tree species, and increase native species diversity, ecosystem resilience, and headwater stream quality on marginal lands.	● Improper reforestation can aggravate land degradation and decrease biodiversity if it does not take local conditions into consideration. ● If there is insufficient diversity in forest age classes during reforestation, there can be a decrease in landscape diversity, resulting in fewer game species. ● Afforestation on abandoned mine lands may require fertilizer that could run off into rivers and lakes.
Disadvantaged communities	● Forests are an important part of the cultural identity of West Virginia, with widespread acceptance of their benefits for recreation, hunting, tourism, and wild forested products (e.g., ginseng). In a 2021 survey, approximately 64% of West Virginians, including those in “coal country,” indicated their support for natural solutions. ● The income from forestry carbon activities can reduce poverty by providing additional income for small landowners.	● Benefits may accrue to wealthy absentee landowners rather than people who live on/use the land locally. ● Community members who do not own land may not benefit economically from reforestation and afforestation activities. ● Without access to information, landowners may enter into suboptimal carbon offset agreements.

Forest Products

Another option for carbon storage is to store carbon in forest-derived products such as buildings and furniture. In 2017, the forest products industry contributed about $3.4 billion in total output and about 19,000 jobs in West Virginia, so support of this industry is important to the state's economy. As illustrated in Figure 2.9, carbon is already stored in many products constructed with wood and is also stored in landfills. Figure 2.10 illustrates how much carbon is stored (the blue area below the "0") by use of forest products as opposed to the carbon generated during steel and cement production. One option is to use engineered wood products such as cross-laminated timber (CLT), which can replace steel and cement in building construction (Figure 2.11). In France, new policies require that any new construction uses at least 50% wood products as one step to meet sustainability goals.

West Virginia's Franklin Elementary School is the first school in the country to be entirely built using CLT, a "mass timber." According to Woodworks Wood Products Council, this one building "resulted in a total potential carbon impact equivalent to taking 600 cars off the road for an entire year" relative to similar buildings constructed of traditional materials. Of this reduction, one-third is due to the carbon sequestered and stored and two-thirds to carbon avoided during manufacturing.

The council estimates that 17,000 buildings each year could use CLT in their construction as opposed to just over 1,000 today. They contend that "it costs about the same to build with wood, yet the environmental benefits are significant and the only key hurdle is awareness and understanding." By other estimates, constructing with wood products can cost 7-20% more than other materials, but can reduce carbon emissions substantially. The academic literature on the use of CLT and other mass timber is mixed. While some believe it can become a key player in reducing CO_2, others question the assumptions that lead to this conclusion. Another study concludes that the potential for this method of carbon storage will vary depending on the country and its evolving market conditions.

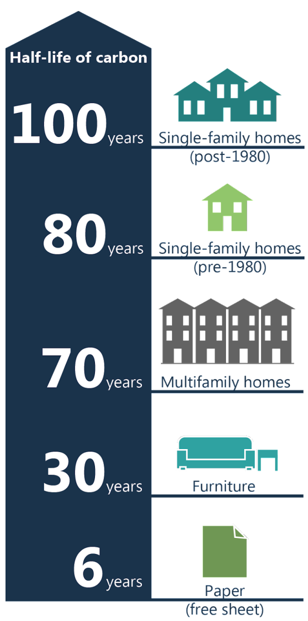


Figure 2.9. Carbon Stocks within Different Wood Products in the United States (U.S. Department of Agriculture, 2022)

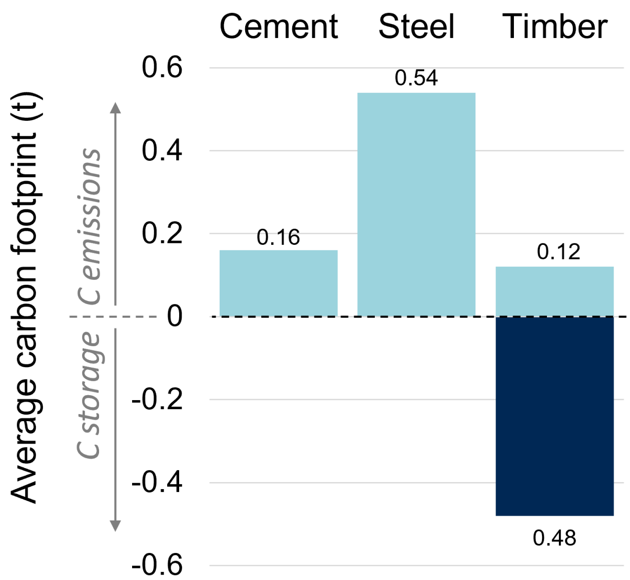


Figure 2.10. Average Carbon Emissions and Storage Capacity of 1 ton (t) of Cement, Steel, and Timber Materials (Data Source: Churkina et al., 2020)

Figure 2.11. Cross-Laminated Timber (APA - The Engineered Wood Association, 2022)

CLT, sometimes called "embodied carbon," is lightweight, strong, easy-to-install, large-scale prefabricated wood that is an alternative to concrete, masonry, and steel and can be used for multi-family and commercial construction. Although not currently manufactured in West Virginia, there are a number of manufacturing facilities throughout the United States. West Virginia University's Appalachian Hardwood Center (AHC), established in 1987 by the West Virginia Legislature, has studied CLT for a number of years.

The AHC is studying which Appalachian region tree species have the most potential for CLT panel production. The focus of their analysis is on yellow-poplar and maple trees. Among the challenges they have identified are that hardwood is not currently designed for structural characteristics and that hardwood costs more than softwood panels. An important recent milestone was the approval of softwood cross-laminated timber by the American National Standards Association (ANSI/APA PRG 320-2019) and its inclusion in the International Building Code.

Box 2.4: What is "Mass Timber"?

Mass timber is "large structural panel products such as cross-laminated timber (CLT), nail-laminated timber (NLT), and dowel-laminated timber (DLT). They are constructed with many pieces of lumber, which is why they offer both forest health and end-use construction benefits. Mass timber can utilize small-diameter logs and even underutilized species, creating high-value end-use markets for what has traditionally been low-value material in U.S. forests. Growing the mass timber market establishes an economic incentive for forest thinning and other landscape restoration efforts that keep forests healthy and reduce the risk of wildfire."

“Mass timber panels are typically between 4 and 12 feet wide, 16 and 60 feet long, and 4 to 12.5 inches thick. They are revolutionary because their strength and other performance capabilities allow them to be used as the main structural material in taller buildings, offsetting more fossil fuel intensive options. Building codes have evolved to recognize these capabilities, and the 2021 International Building Code (IBC) allows mass buildings up to 18 stories.”

Source: Woodworks - the Wood Products Council, 2021

In addition to engineered lumber, there are a number of other bio-based products that can be used in building construction. The carbon emissions/sequestration potential for each is provided in Figure 2.12.

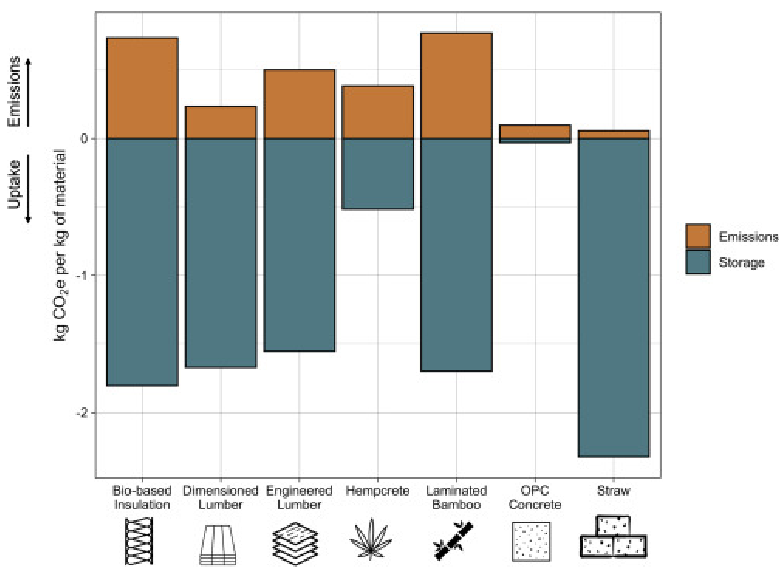


Figure 2.12. Net Carbon-Storage Potential of Building Materials (Pompomi et al., 2020)

There are additional decisions and practices made by the wood products industry that can further affect carbon removal and emissions. The end products in which the wood carbon is ultimately stored influences the amount of time before the carbon is released back into the atmosphere (Figure 2.9). Additionally, low-impact harvesting and forest residue management and utilization can decrease carbon emissions. After disturbance or harvesting, forest residue decomposes, releasing carbon back into the atmosphere. Minimizing forest residue and utilizing any forest residue produced (for thermal energy, biochar, or pulp products) can increase its carbon storage time or displace nonrenewable fossil fuel use.

Agriculture and Soil Management Practices

Agriculture and soil management can play a major role in reducing CO_2 emissions. Although agriculture is a major contributor to greenhouse gas emissions, the adoption of certain management practices can reduce its emissions and those of other sectors and industries. Box 2.3 provides an example of how agriculture can play a role in carbon offsets and insets.

In West Virginia, agricultural commodities (not including timber) contribute $800 million annually to the state's economy. Ninety-eight percent of farms in West Virginia are small and family-owned, and over two-thirds of farms produce livestock or livestock-related products. With 3.5 million acres in agricultural land in WV, the average farm size in 2020 was 154 acres, and in 2012, though the average economic output for West Virginia farms was $38,000 (the lowest of all 50 states), three in four farms made less than $10,000 in sales. So, West Virginia differs from much of the Midwest (which has primarily large, corporate agriculture) in how farms are managed and the products they produce.

Box 2.5: Carbon Offsets vs. Insets in Agriculture

"Carbon credits are designed to be purchased by carbon emitters to offset their emissions while maintaining overall emission below certain thresholds, or to reduce their overall carbon footprint. Some programs also offer farmers the possibility of selling carbon insets to downstream companies that use agricultural commodities in their supply chains. For example, food and beverage companies interested in lowering their supply chain overall emissions could purchase carbon insets from agricultural producers.

"Carbon insets are not designed to offset emissions in other parts of the supply chain, but rather reduce its overall GHG emission footprint. A major difference between practices that generate carbon offsets and those that generate carbon insets is their permanence: while the former need to be maintained for long periods of time, the latter might be only temporarily implemented. Another major difference is that while an agriculture carbon credit can only offset one ton of carbon emitted somewhere else, a temporary carbon inset can be claimed by multiple actors within the supply chain and across supply chains. For example, carbon insets in soybean production can be claimed within the same value chain by the crushing plant, the food processing plant that uses soybean oil, the retailer that sells the processed food and the oil; as well as across value chains by hog producers, biodiesel plants and gas stations, and cosmetic products using soy derivatives.**"**

Source: How to Grow and Sell Carbon Credits in US Agriculture, Iowa State University Extension and Outreach, November 2021

An analysis by the Farmland Information Center found that total farmland in West Virginia is decreasing due to development pressures; the analysis also found that the threat of farmland loss is higher than the state's policy response (Figure 2.13). Increased awareness of agricultural carbon offset programs and other conservation programs may slow this loss by providing additional sources of revenue to family farmers. Abandoned mine lands (AML) may be an additional option for conservation. [Regenerative farm techniques](#) (such as the use of cover crops, no-till farming, and mixed-use agriculture) on AML may increase the amount of land available for agriculture in West Virginia. Only about 25% of AML land, however, may be suitable for agricultural activities, according to [a WVU analysis](#).

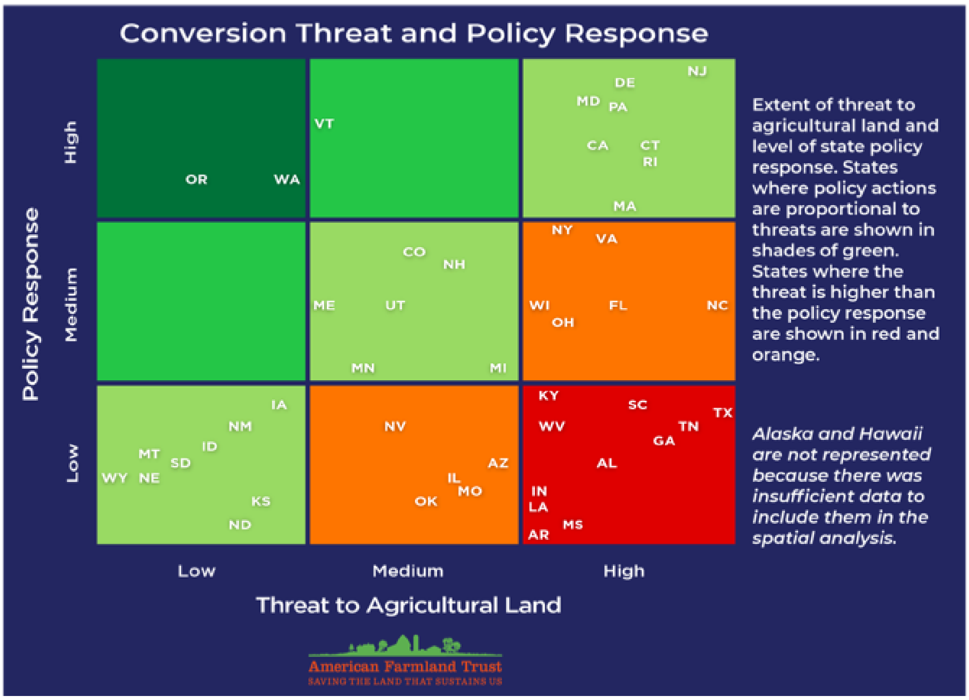


Figure 2.13. Threat to Agricultural Land and Policy Response, by State ([American Farmland Trust](#), 2020)

Pasture Management

Pastures are central to the agricultural land use and economy of Appalachia. Almost half [(46%)](#) of unwooded farmland in West Virginia is pastureland for livestock or hay production, comprising the state's second largest agricultural commodity. Despite the clear importance of pasturelands in West Virginia, however, [many pastures are not managed effectively](#), leading to low productivity such that the potential to support animal productivity is not optimal. Well-managed pastures assess soil yield potential and soil fertility to establish forage crops.

For example, when grasslands are [overgrazed](#) by cattle, they become degraded, store less soil organic carbon, and can become a source of ongoing carbon losses. As with other crops, adding organic amendments, especially compost, can help increase soil carbon storage on pasturelands. Also, farmers can use an alternative method, rotational grazing, to increase soil organic carbon while at the same time reducing their need for alternative feed sources, resulting in increased profitability.

Few farmers in West Virginia, however, use rotational grazing. A 2014 survey found that the top perceived barriers to implementing rotational grazing by farmers were livestock access to water, cost of fencing, and increased time and labor. Since most farmers are part-time, they often lack the funding, time, and motivation to implement practices that enhance soil carbon sequestration.

Current Federal and State Programs

Today, there are a number of federal programs supplemented by programs in some states that provide economic incentives for specific agricultural practices, many of which increase soil carbon sequestration (Table 2.4). Farm policy is currently subject to the Farm Bill and to USDA programs through the Farm Service Agency, Natural Resource Conservation Service, and Risk Management Agency. These U.S. federal agricultural programs are administered through state agencies such as West Virginia's State Office.

The USDA provides payments to landowners for implementing agricultural practices, which often has the co-benefit of increasing CO_2 sequestration on farmlands. For example, the USDA is currently reviewing a proposal to fund pilot projects for the new Partnerships for Climate-Smart Commodities: "Through this new program, USDA will finance partnerships to support the production and marketing of climate-smart commodities via a set of pilot projects lasting one to five years. Pilots will provide technical and financial assistance to producers who implement climate-smart practices on a voluntary basis on working lands; pilot innovative and cost-effective methods for quantification, monitoring, reporting and verification of greenhouse gas benefits; and market the resulting climate-smart commodities."

The USDA already supports many well-established programs that promote the co-benefit of CDR, such as the Conservation Reserve Program that pays farmers to take cropland out of production and plant grass or trees instead. It was originally implemented to influence crop prices and to decrease soil erosion, but it also increases soil organic carbon storage, which has become more of a focus over the last 15 to 20 years. The Environmental Quality Incentives Program, Conservation Stewardship Program, and Regional Conservation Partnership Program provide funding for implementing CDR-enhanced farming.

Whether or not a farmer could participate in both a conservation easement program and carbon offset market would depend on how land and resource rights are defined in each agreement. Also, if their land is already sequestering carbon at a high rate because of their conservation efforts, additional carbon sequestered for selling carbon credits may be limited. Federal conservation programs, instead of selling carbon, pay farmers for adopting new management strategies that enhance the resilience of their land and protect environmental resources.

The Food and Agriculture Climate Alliance recommends a performance-based 45Q tax credit and a USDA-managed Commodity Credit Corporation carbon bank. This is discussed in Box 2.6.

Box 2.6. What is a Conservation Easement, and How Does the USDA's Agricultural Conservation Easement Program (ACEP) Work?

"What is ACEP?

ACEP helps landowners, land trusts, and other entities protect, restore, and enhance wetlands or protect working farms and ranches through conservation easements. Under the Agricultural Land Easements component, NRCS helps American Indian tribes, state and local governments, and nongovernmental organizations protect working agricultural lands and limit nonagricultural uses of the land. Under the Wetland Reserve Easements component, NRCS helps to restore, protect, and enhance enrolled wetlands.

. . .

"What are the benefits of ACEP?

• Keeps agricultural land in family hands.

• Provides a means to remove marginal cropland from production.

• Provides income.

• Protects our nation's best agricultural soils or grasslands.

• Preserves wildlife habitat and protects biodiversity, including for threatened and endangered species.

• Protects and restores wetlands and improves water quality.

• Sequesters carbon and helps reduce greenhouse gases.

"How does ACEP work?

Landowners who enroll in ACEP retain private ownership of their land but must follow certain land use requirements. They must agree to maintain a specific use of their lands.

Examples include:
• Agreeing to limit non-agricultural use of land in an agricultural land easement.
• Agreeing to cease agricultural activity on a wetland easement to protect the conservation value of the wetlands.

Easement holders may lease the rights to undeveloped recreational uses like hiking, bird watching, hunting, and fishing.

NRCS [Natural Resources Conservation Service] may provide landowners enrolled in easements with both financial assistance and one-on-one technical support to fit their specific land use goals. Easements are also annually monitored to ensure compliance with allowable land uses.

"Easements do not:
• 'Take over' land in private ownership – all enrollments are voluntary.
• Cause landowners to lose access to their land.
• Allow public access-unless specifically agreed to by the landowner.

• Shift the tax burden of the enrolled land to the public."

Source: Agricultural Conservation Easement Program (ACEP): Is ACEP Right for Me?, U.S. Department of Agriculture, September 2021

Box 2.7. Food and Agriculture Climate Alliance Proposed Policy Options

The Food and Agriculture Climate Alliance recommends a performance-based 45Q tax credit and a USDA-managed Commodity Credit Corporation carbon bank. Specifically,

- "A performance-based tax credit for carbon sequestration modeled after 45Q
    - The Department of the Treasury, in consultation with USDA, should develop a tax credit modeled after Internal Revenue Code Section 45Q. 45Q provides a tax credit on a per-ton basis for qualified captured carbon dioxide.
    - The tax credit should be transferable, allowing maximum flexibility for participants.
    - Relevant USDA agencies should play a significant consultative role in developing a policy guidance document covering measurement and verification that could be used for public incentives and by private markets.
- "A USDA-led Commodity Credit Corporation (CCC) carbon bank
    - The carbon bank would establish a price floor for carbon sequestration and GHG reductions. This would be contingent upon a significant increase in the CCC borrowing authority to ensure that the establishment of such a bank would not impede critically important ongoing operations of the CCC, including farm programs, crop insurance and mandatory conservation programs.
    - When developing the program, USDA should mitigate potential market impacts and ensure that the program is not overly complicated or burdensome.
- "Provide a one-time payment for early adopters
    - Eligibility for a one-time bonus payment would be contingent upon participation in a new, USDA-approved incentive program or an existing conservation program.
    - When determining the definition of "early adopter," NRCS should utilize a sliding scale based on the length of time, number and type of practices adopted by a producer.
    - Funding should come from a one-time appropriation to remain available until expended.
    - Participants would self-certify using documentation based upon, but not limited to:
        - Satellite imagery.
        - Soil testing.
        - Previous participation in NRCS, state or third-party certification or conservation programs."

Agriculture Industry Programs

In the food and beverage industry, 90% or more of greenhouse gas emissions can come from indirect emissions within the agricultural supply chain. Some companies are voluntarily taking action to reduce their carbon footprints. For example, Kroger is introducing carbon-neutral eggs, and Anheuser-Busch is partnering with a non-profit, Carbon Neutral, to purchase carbon offsets and invest in renewable energies to meet carbon-neutrality for one of their beers.

Technical and Economic Challenges to Farmer Participation

Participating in the agricultural carbon offset market is technically complicated, however, and the economic incentives are not always sufficient to encourage farmers to participate—even if they are aware of and interested in such programs. For farmers to sell credits for the carbon stored in their soil, this carbon has to be measured and verified, which can be prohibitively costly and time-intensive. Technical challenges (including the requirements to measure and verify soil carbon sequestration) and financial challenges (including the current low market value of agricultural carbon—approximately \$10-15 per ton of CO_2 captured) prevent more farmers from considering selling carbon credits in their agricultural plans. These barriers may make federal conservation programs more enticing, as the upfront costs of management would be shared by the federal government, and farmers would not need to rely on selling credits to private entities in a volatile carbon market.

To help reduce entry barriers into voluntary environmental credit markets for farmers, ranchers, and private forest landowners, there is bipartisan support for improving these programs through legislation such as the Growing Solutions Act (S. 1251, H.R. 2820), which would establish a voluntary Greenhouse Gas Technical Assistance Provider, and the Third-Party Verifier Self-Certification Program. Both West Virginia senators supported this legislation when it passed the Senate.

Table 2.4. Federal and State Economic Incentives to Encourage Specific Agriculture Practices (West Virginia University, 2022)

Economic Incentive Mechanism	State - Country - Application Agency	Cost of Incentive	Economic Prosperity Implications
Federal Programs			
Conservation Reserve Program (CRP)	United States - Farm Service Agency (FSA)	Diversified "rental rate" dependent on where land is located; rates are available for all 55 WV counties	Job creation not studied; economic prosperity variable by contract length and valuation of land
Environmental Quality Incentives Program (EQIP)	United States - USDA	Total obligation in WV for FY2020 is $15.66 million; total U.S. obligation is $1.83 billion	Financial assistance for addressing natural resource concerns regarding air and water quality, including agricultural and soil qualities
Farm and Ranch Lands Protection Program (FRPP)	United States - USDA	No obligation in WV for FY2020; total U.S. obligation is $11.2 million	Purchasing of developmental rights to farmland
Agriculture Management Assistance (AMA)	United States - USDA	Determined by total number of participation in a given fiscal year	Covers up to 75% of the cost of installing conservation practices, up to $50,000 per participant in a given fiscal year
Regional Conservation Partnership Program (RCPP)	United States - USDA	$300 million standalone funding created through the 2018 Farm Bill; $225 million allocated for projects in 2022	Eligible organizations apply for grant funding that promotes solutions to conservation challenges in agriculture and non-industrial private forest land
State Programs			

Economic Incentive Mechanism	State - Country - Application Agency	Cost of Incentive	Economic Prosperity Implications
Healthy Soils Initiative	California - United States - CA Dept. of Food and Agriculture	Funded through the state's cap-and-trade program on carbon, receiving $40.5 million in funding from 2016-19	Valuations determined by methodology as established by the CA Air Resource Board and USDA-NRCS, resulting in varied economic impact
Carbon Farming Tax Credit	New York - United States	Tax credit model to maximize sequestration through agricultural measures, proposal notes various cost outputs	Did not pass through NY Assembly (2017), but did receive a $50,000 study incentive in the state budget; no further information available
Conservation Excellence Grant Program	Pennsylvania - United States	HB 1517 Fiscal Note cites "no adverse impact on Commonwealth funds,"adding that all funding would come through tax crediting and funding through the PA General Fund	"Financial assistance" program to help the agriculture community with issues including "cover crop" management; no determination on job creation
Sustainable Farms and Fields Grant Program	Washington - United States	FY2019-21 Fiscal Note cites $168,739 in "operating expenditures" and $0 for budget expenditures; total increases to $262,698 in 2023-25	Direct grant program to the agricultural sector for certain actions, as defined, including "carbon farming"
Carbon Sequestration Certification Program	Oklahoma - United States - OK Conservation Commission (OKCC)	Carbon program is "fee-funded," with attributions available on OKCC website	No job valuation; economic impact through carbon offset programming
Resource Enhancement And Protection (REAP) Grant Program	Pennsylvania - United States	FY2019 total cost measurement was ~$37.7 million, as	Income tax credits to offset implementation costs of conservation

Economic Incentive Mechanism	State - Country - Application Agency	Cost of Incentive	Economic Prosperity Implications
		defined by annual state report	practices directly to landowners
Agricultural BMP (VACS) Program	Virginia - United States - VA Dept. of Conservation and Recreation	Administration and operations cost valuations for FY2022 are $6,521,091	Direct cost-share payments to landowners of certain sectors for management of land in line with recommended conservation standards

Equity Barriers to Farmer Participation

Notwithstanding the federal and state programs, certain equity barriers exist in making USDA and other agricultural programs equally available to all small farmers. These inequities affect the ability of farmers of color to profit from carbon credit offset programs (as discussed in Section 6, below). The USDA admitted its "checkered" racially discriminatory past in a 2010 litigation settlement.

In an attempt to overcome this historical discrimination, the USDA released a plan to address inequality and discrimination: the Equity Action Plan. There are agricultural and forestry programs designed to assist disadvantaged farmers; these include the Outreach and Assistance for Socially Disadvantaged Farmers and Ranchers program, Farm Service Agency loan down payment grants, and other loan programs for underserved communities. Yet, concerns about discrimination issues persist today. The Biden Administration's American Rescue Plan provided for up to $4 billion in minority farmer loan forgiveness. However, a federal judge issued a temporary injunction against implementing this program in a lawsuit filed by white farmers claiming reverse discrimination.

Table 2.5. Opportunities and Challenges of Agriculture to Reduce Carbon Dioxide in West Virginia (West Virginia University, 2022)

	Opportunities	**Challenges**
Science and technology	● Many agricultural practices (e.g., conservation tillage, deep-rooted cultivars, cover cropping, perennial systems) can improve overall carbon sequestration capacity and soil health, and limit	● The likelihood of re-releasing carbon stored in soils is high compared to other methods. Conservation tillage can increase nitrous oxide emissions, potentially reducing the greenhouse gas benefits. ● Measuring soil carbon stocks and

	emissions released by agricultural machines.	sequestration is challenging, and there is inconsistency in the protocols used.
Economic prosperity	• Enhanced soil carbon improves soil health, leading to higher yield and economic production from farmlands. • Farmers can sell carbon credits for the carbon sequestered in soil. Federal programs share the costs of improved management, as opposed to selling carbon in a volatile carbon market.	• The high costs of measuring and verifying soil carbon credits have prevented some farmers from participating in the voluntary carbon trading market.
Environmental & conservation impact	• Increases in soil carbon can also increase soil health, crop yield, and soil water filtration and retention, reduce soil erosion, increase biodiversity, and decrease the amount of fertilizers needed.	• Some methods for increasing soil carbon storage can have negative effects, such as the addition of compost and manure that impact streams and downstream water.
Disadvantaged communities	• Agricultural yields can increase due to soil carbon enrichment, thus improving the living conditions of farmers. • Potential payments for carbon sequestered in their soil can support family farms.	• Demanding institutional and technical requirements and long-delays in carbon market payments may discourage economically-disadvantaged community participation and put small-scale agriculture at a competitive disadvantage in carbon markets compared with large-scale industrial agriculture.

Inland Wetlands Management Practices

Wetland restoration is complicated, as each wetland needs to be reviewed independently. The WV Department of Environmental Protection (WVDEP) is already beginning this process. They've found that

> "The single most important threat to wetlands in West Virginia is land conversion from natural to developed land uses as part of general economic development. Construction, extractive industries, and floodplain development all contribute to wetland loss in the state. Pollution, artificial drainage, and invasive species degrade existing wetlands. Climate change, which is bringing an increased frequency of both drought and extreme

storm events, threatens wetlands while at the same time underscoring their importance in helping to stabilize the hydrologic cycle."

Wetlands in West Virginia have the potential to sequester and store carbon over the long term. Additionally, wetlands provide many other ecosystem services that are particularly important to the state, such as flood control and water purification (Figure 2.14). There is potential for both minor and major wetland restoration activities, including the possibility of creating duck-hunting and tourist areas that may bring revenue to rural communities. Some wetlands in West Virginia already serve as economic engines, bringing in tourism and recreation revenue (see Box 2.8).

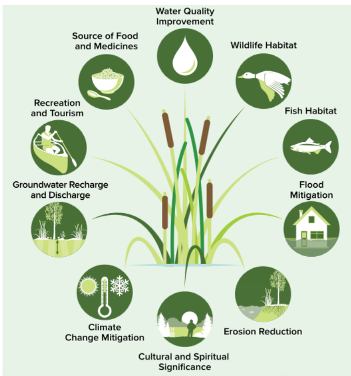


Figure 2.14. How People Benefit from the Ecosystem Services Provided by Wetlands (Ontario Ministry of Natural Resources and Forestry, 2017)

Box 2.8. Canaan Valley National Wildlife Refuge

The best example in West Virginia of potential economic gains from tourism is the Canaan National Wildlife Refuge, the nation's 500th refuge. The refuge was established in 1994 with 86 acres but came into its own with the purchase of an additional 12,000 acres in 2002. Today, it is 17,000 acres, 8,500 of which are wetlands. As described and pictured by the U.S. Fish and Wildlife Service (USFWS),

"A patchwork of 23 wetland types, including bogs, shrub swamps and wet meadows carpet the valley floor. At about 8,500 acres, this is the largest wetland complex in the state of West Virginia, and is a regionally significant wetland complex within the southern Appalachians.

"The ecological functions of wetlands provide valuable services to people. Wetlands absorb water like a sponge, slowing it down during heavy storms, thereby reducing downstream flooding. During times of drought wetlands slowly release water. They filter sediment, trash and pollutants. Without wetlands we would need more water treatment plants, flood control and bank stabilization projects, and relief from natural disasters. Canaan Valley's wetlands provide great habitat for a diversity of dragonflies and damselflies."

Of the 73,500 annual visits in 2017, about 40% of visitors come from 50 or more miles away. These visitors participated in a wide variety of activities, as illustrated by the figure below. Such activity resulted in economic benefits including 33 jobs and $2.7 million in revenue, most from out-of-town visitors. Details are provided below.

Table 1. Canaan Valley NWR: 2017 Recreation Visits

Activity	Residents	Non-Residents	Total
Non-Consumptive:			
Pedestrian	11,325	16,987	28,312
Auto Tour	-	-	-
Boat Trail/Launch	64	96	160
Bicycle	4,789	2,053	6,842
Photography	17,500	7,500	25,000
Interpretation	511	341	852
Other Recreation	1,679	1,679	3,358
Visitor Center	5,675	631	6,306
Hunting:			
Big Game	740	1,110	1,850
Small Game	47	111	158
Migratory Birds	90	184	274
Fishing:	273	117	390
Total Visitation	**42,693**	**30,808**	**73,501**

Table 2. Canaan Valley NWR: Visitor Recreation Expenditures (2017 $,000)

Activity	Residents	Non-Residents	Total
Non-Consumptive	$479.30	$1,899.80	$2,379.10
Hunting	$21.20	$81.80	$103.00
Fishing	$8.70	$8.70	$17.40
Total Expenditures	**$509.10**	**$1,990.40**	**$2,499.50**

Table 3. Canaan Valley NWR: Local Economic Contributions Associated with Recreation Visits (2017 $,000)

Economic Contribution	Residents	Non-Residents	Total
Economic Output	$569.70	$2,087.60	$2,657.30
Jobs	8	26	34
Job Income	$153.60	$550.80	$704.40
State and Local Tax Revenue	$52.60	$197.90	$250.50

Sources: U.S. Fish and Wildlife Service, Canaan Valley National Wildlife Refuge website, 2022; Banking on Nature: The Economic Contributions of National Wildlife Refuge Recreational Visitation to Local Communities, 2017, 2019; The Economic Contributions of Recreational Visitation at Canaan Valley National Wildlife Refuge, 2019

Table 2.6: Opportunities and Challenges of Wetlands to Reduce Carbon Dioxide in West Virginia (West Virginia University, 2022)

	Opportunities	Challenges
Science and technology	• Wetlands of the Eastern Mountains and Upper Midwest store the most carbon, accounting for nearly half of the wetland carbon in the United States.	• Wetlands both sequester carbon and emit methane (another greenhouse gas), leading to questions about their overall impact on climate change. One study, however, found that the creation and restoration of wetlands can sequester carbon and provide other ecosystem services without concern about the consequences of climate change impacts.
Economic prosperity	• Boardwalks and other constructed development in the wetland/peatland areas provide economic opportunity (tourism) and educational opportunities without disturbing the wetlands; see Box 2.2 for a detailed West Virginia example. Conservation activities promote volunteerism, science-based educational opportunities, and jobs for environmental and conservation professionals.	• Once wetlands are in place, the opportunities for other economic development activities may be limited, as the areas are then protected by the Clean Water Act; exceptions can include agriculture and forestry activities, though these activities require a permit from the Army Corps of Engineers.
Environmental & conservation impact	• Preservation and restoration of wetlands provides clean water, flood protection, wildlife habitat, carbon storage, and recreation opportunities to West Virginians.	• If not properly restored or created, wetland restoration failures can lead to more erosion, invasive species colonization, over-abundance of predators, and other ecological challenges. Depending on the hydrology (movement of water) in restored wetlands, they could release methane (CH_4), which is a potent greenhouse gas.
Disadvantaged	• The improved environment resulting from wetland	• It may be costly to restore wetlands in impoverished areas, which often have

communities	restoration will increase wildlife populations and clean the air and water in surrounding communities. ● Wetlands can be peaceful and inspirational places for humans to visit and recreate.	other environmental stressors such as environmental pollution or inadequate sewage and stormwater management systems.

3: Bioenergy with Carbon Capture and Storage (BECCS)

Bioenergy with carbon capture and storage (BECCS, with the "*s*" sometimes referring to "sequestration") focuses on taking waste biomass, including agricultural waste and municipal waste, and converting it into valuable products such as bioenergy (Figure 3.1) or biochar (Figure 3.2). In this policymaker guide, we use the broader view of BECCS as described by the [National Academies of Sciences, Engineering, and Medicine](), which includes

> "(1) biomass combustion to thermal and electrical power with carbon capture and sequestration (traditional BECCS)
>
> (2) biomass thermochemical conversion to fuel with biochar soil amendment, and
>
> (3) biomass fermentation to fuel with carbon capture and sequestration."

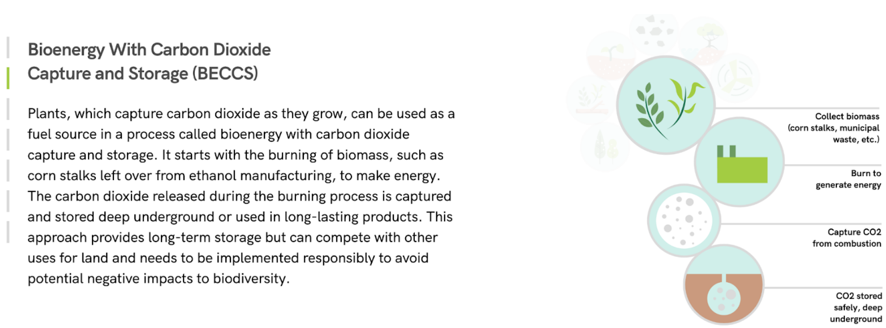


Figure 3.1. How Bioenergy with Carbon Dioxide Capture and Storage Works (adapted from [Chan Zuckerberg Initiative](), 2022)

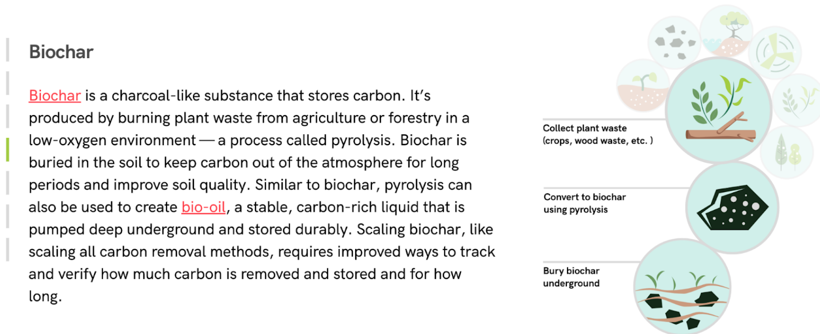


Figure 3.2. What is Biochar? (adapted from [Chan Zuckerberg Initiative](), 2022)

Unlike natural CDR processes, BECCS requires a method for storing the CO_2 that is captured. One advantage, however, is that BECCS can take advantage of waste generated by current economic activities, such as the forest product and agricultural industries, which are active in West Virginia.

What is the Potential of BECCS in West Virginia?

In West Virginia, the biomass available for use in bioenergy systems includes three potential categories of feedstocks:

- Forestry: whole-tree biomass and logging residues
- Agriculture: energy crops and crop residues
- Other wastes: municipal solid waste, secondary crop residues, and manure

Figures 3.3 and 3.4 provide the annual and cumulative carbon sequestration potential if the bioenergy is converted into electricity, and Figures 3.5 and 3.6 show the results if converted to a liquid fuel. According to this data, forestry is comparable to agriculture in terms of its potential contribution to CO_2 sequestration for both bioenergy converted to electricity and to fuels. Detailed information on how these estimates were developed can be found in Appendix D.

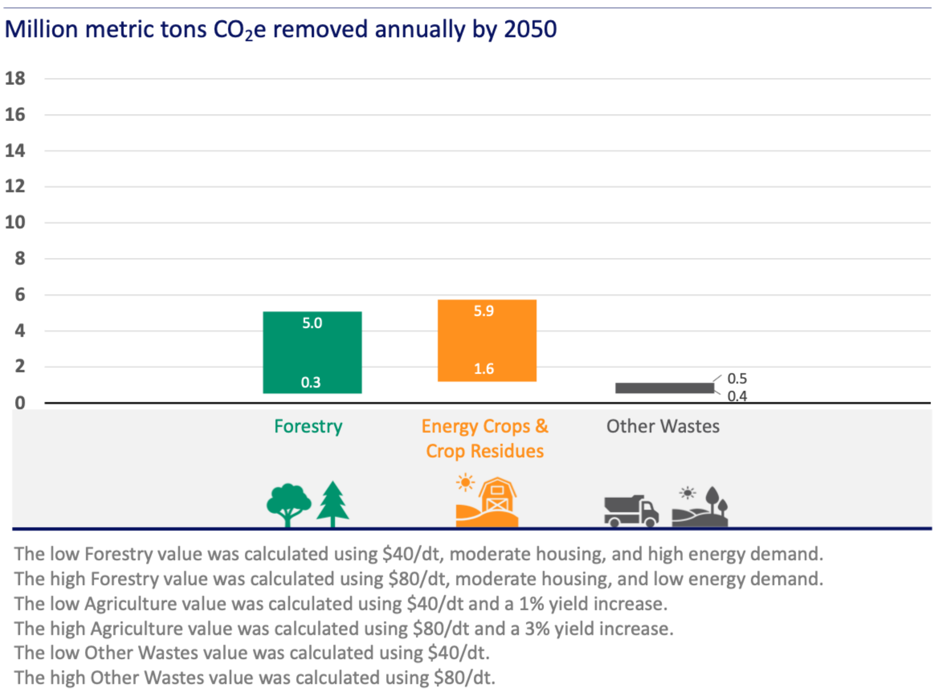
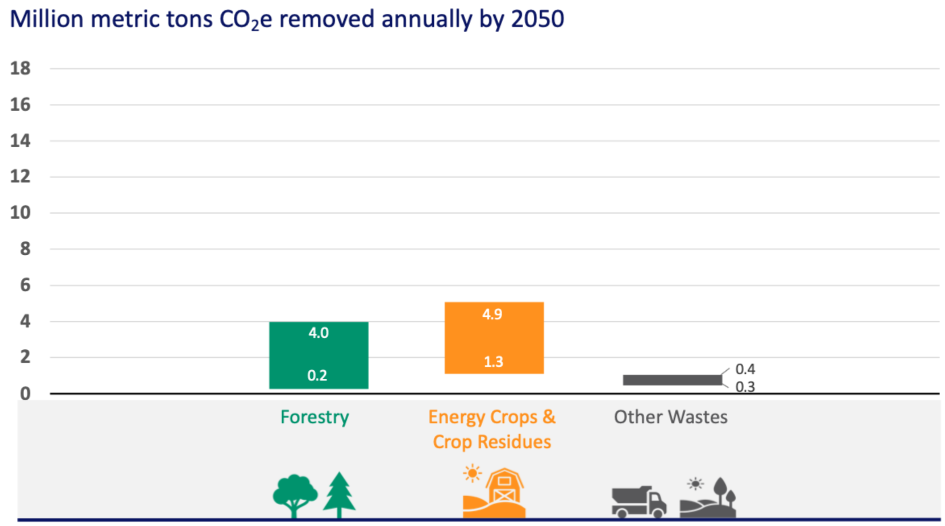


Figure 3.3. West Virginia's Technologically Enhanced Natural Annual Carbon Sequestration Potential: Bioenergy to Electricity with Carbon Capture & Storage (BECCS), by 2050 (West Virginia University, 2022)

Figure 3.4. West Virginia's Technologically Enhanced Natural Cumulative Carbon Sequestration Potential: Bioenergy to Electricity with Carbon Capture & Storage (BECCS), 2022-2050 (West Virginia University, 2022)



The low Forestry value was calculated using $40/dt, moderate housing, and high energy demand.
The high Forestry value was calculated using $80/dt, moderate housing, and low energy demand.
The low Agriculture value was calculated using $40/dt and a 1% yield increase.
The high Agriculture value was calculated using $80/dt and a 3% yield increase.
The low Other Wastes value was calculated using $40/dt.
The high Other Wastes value was calculated using $80/dt.

Figure 3.5. West Virginia's Technologically Enhanced Natural Annual Carbon Sequestration Potential: Bioenergy to Liquid Fuels, by 2050 (West Virginia University, 2022)

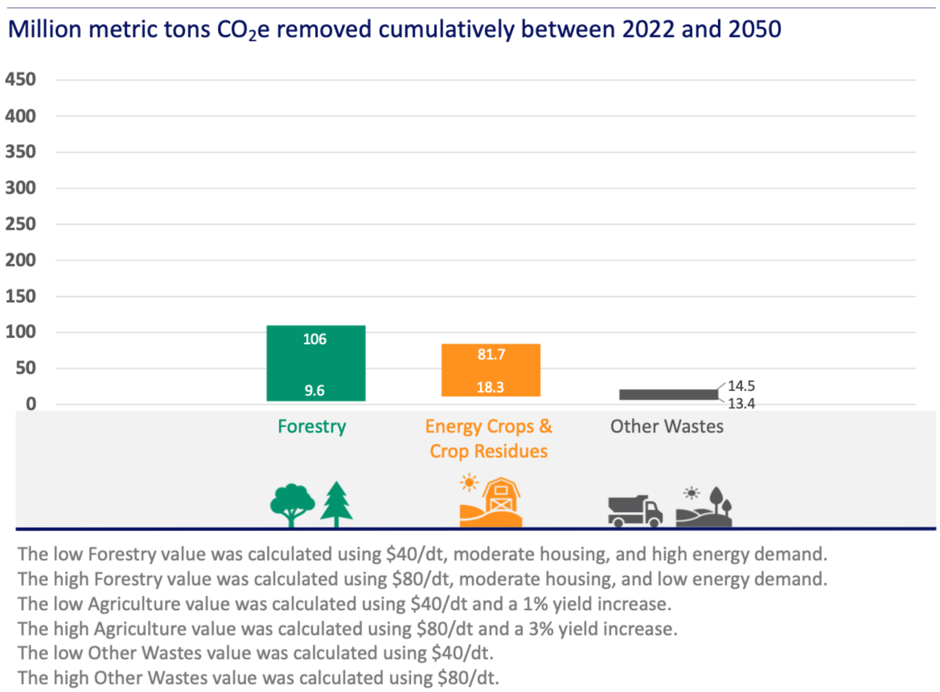


Figure 3.6. West Virginia's Technologically Enhanced Natural Cumulative Carbon Sequestration Potential: Bioenergy to Liquid Fuels, 2022-2050 (West Virginia University, 2022)

As shown in Table 3.1, the annual total economic impact is estimated to be $446-1,770 million in economic output and 746-2,960 total jobs per year for biomass to electricity. If instead, that same biomass is converted into fuels, the annual total economic impact is estimated to be $135-697 million and 295-1525 jobs (Table 3.2). Detailed information on this analysis can be found in Appendix J.

Table 3.1. Annual Economic Impact of Biomass to Electricity Spending in West Virginia (West Virginia University, 2022)

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	276–1,094	170–675	446–1,770
Employment (jobs)	183–724	564–2,236	746–2,960
Labor Income ($, millions)	30–120	39–156	70–277

Total Taxes ($, millions)	5–19	4–17	9–36

Note: Tax Revenue impact includes sales, personal income, property, and corporation net income taxes.

Table 3.2. Annual Economic Impact of Biomass to Fuels Spending in West Virginia (West Virginia University, 2022)

	Direct Impact	**Indirect & Induced Impact**	**Total Economic Impact**
Output ($, millions)	99–512	36–185	135–697
Employment (jobs)	68–354	227–1,171	295–1,525
Labor Income ($, millions)	10–50	10–52	20–102
Total Taxes ($, millions)	1–5	1–5	2–10

Note: Tax Revenue impact includes sales, personal income, property, and corporation net income taxes.

Biomass Energy Plants

Biomass energy plants vary a great deal in their operation. Many sources of biomass can be converted through different types of technology to a variety of energy products, including hydrogen, grid electricity, liquid fuels, biochar, and renewable natural gas (Figure 3.7).

Biomass to Electricity

Unlike a traditional power plant, the power generated via BECCS does not need to provide energy for many businesses or consumers via an electrical grid. BECCS can instead focus on very local needs—perhaps that of just one business or neighborhood, for example. This would reduce costs and emissions related to the transportation of the biomass, which might otherwise add to greenhouse gas emissions. So, the use of BECCS is not a “one size fits all” approach.

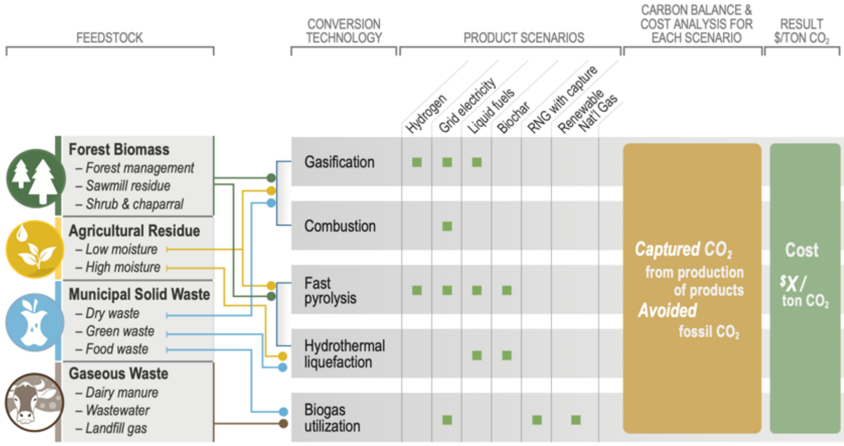


Figure 3.7. Diagram Linking Biomass Type to Conversion Technology (Lawrence Livermore National Laboratory, 2020)

Biomass to Fuel

Large-scale biological biomass-to-fuel and biochar technology is commercially available today. In addition, the ethanol and biodiesel produced from bioenergy plants is used in vehicles. The chief challenge is that today few bioenergy plants have carbon capture technologies that collect the CO_2 generated in the process. Biofuel used in cars, trucks, and planes, however, do displace traditional petroleum products, and when biofuels grow they absorb CO_2, resulting in overall decreased carbon emissions (Figure 3.8). There are, however, a number of challenges related to the production and use of biofuels (Figure 3.9).

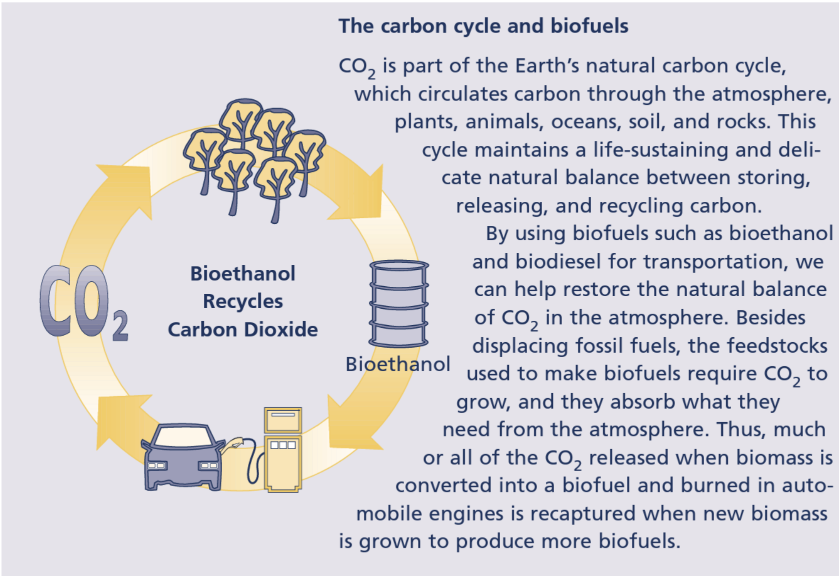


Figure 3.8. How Biofuels Recycle Carbon Dioxide (National Renewable Energy Laboratory, 1999)

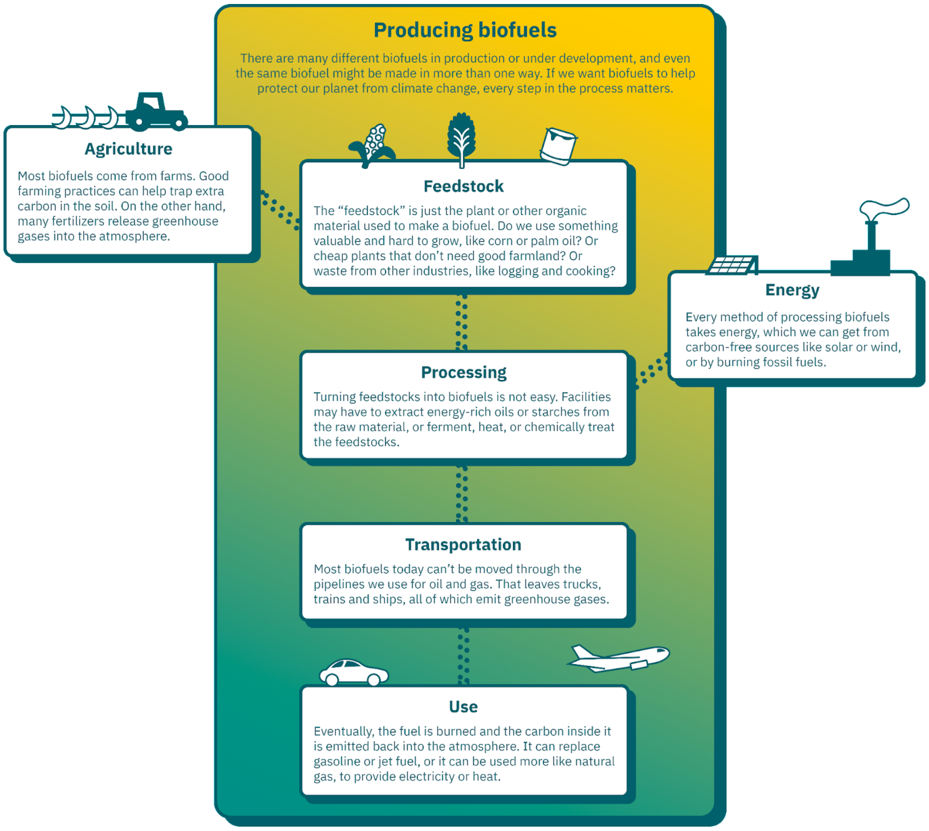


Figure 3.9. Biofuel Production Opportunities and Challenges (Massachusetts Institute of Technology, 2020)

Figure 3.10 provides information on wood and biomass energy consumption in relation to other sources of renewable energy in West Virginia. As can be seen, this consumption has varied over time. The drop in wood and biomass waste consumption in 2015 may have resulted when West Virginia dropped its renewable energy portfolio standard (RPS) that year—a standard that had been in place since 2009. That standard had "required investor-owned electric utilities and retail suppliers with more than 30,000 customers to obtain 25% of their electricity from eligible alternative and renewable energy resources by 2025." About 45% of West Virginia's end-use sector energy is for industrial needs.

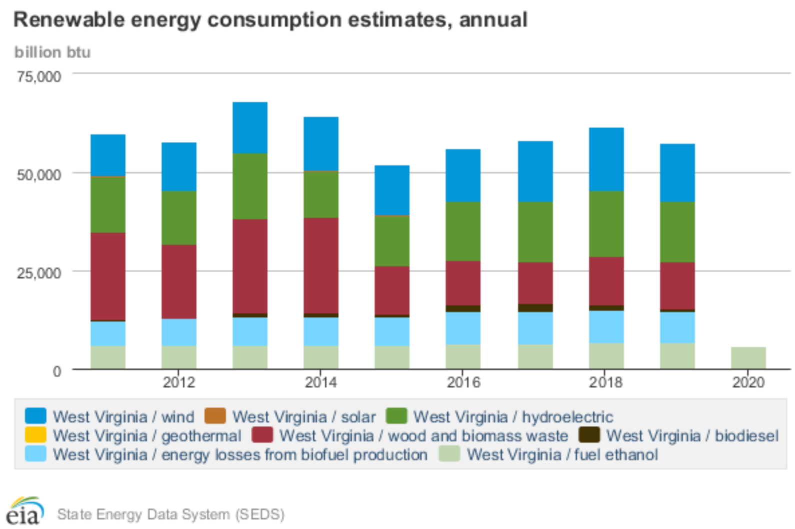


Figure 3.10. Wood and Biomass Waste Energy Consumption, West Virginia, 2011-2020 (Energy Information Administration, 2022)

Figure 3.11 illustrates that most current bioenergy consumption is in the industrial sector. Note that the carbon emitted during the combustion of biomass is likely not captured.

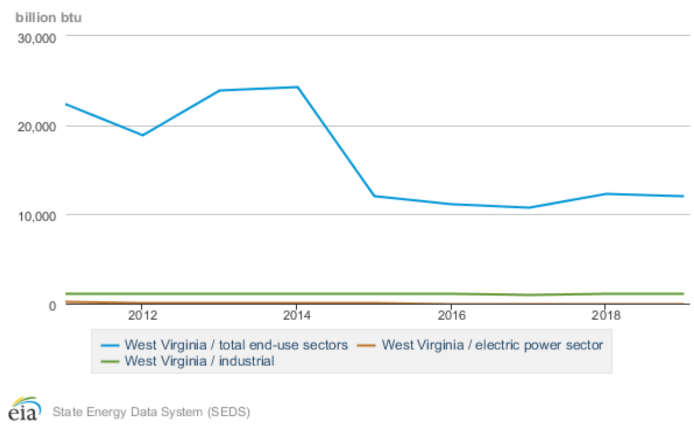


Figure 3.11. Wood and Waste Consumption Estimates by Sector, Annual, West Virginia, 2011-2020 (Energy Information Administration, 2022)

In addition to forestry waste and agricultural waste, other sources of biomass in West Virginia are organic waste feedstocks such as municipal sewage sludge (human waste), animal manure, agri-food process residue, and organic municipal solid waste (e.g., food waste). One possible source of waste in West Virginia is the poultry industry, particularly in Hardy County. WVU is currently conducting a study to quantify biomass energy feedstocks, including poultry litter and municipal sewage sludge in this county.

Concerns about Land Use Conflicts

The primary challenge with BECCS is its interactions and tradeoffs with existing food, water, energy, biodiversity, and social systems (FWEBS). For example, land used today to produce feed crops and animal products could instead be used to grow crops for bioenergy, as illustrated in the "business as usual" scenario of Figure 3.12. An aggressive strategy for BECCS would divert that land for sequestration purposes instead. The key for a successful strategy is illustrated by the conservation scenario that provides balanced use of the land so that all societal needs can be met.

This is the approach favored by the Mid-Atlantic Sustainable Biomass Consortium (MASBio), a regional network of universities, businesses, and governmental organizations led by West Virginia University. This group is dedicated to delivering a sustainable and economically feasible "biomass for value-added products" system in the Mid-Atlantic region of the United States. The project focuses on the over 10 million acres of mined and marginal agricultural lands that could be reclaimed to produce biomass crops seasonally. Utilizing this option would avoid the issue of competition with food crops on existing cultivated areas. The project is also focused on the use of more than 8 million dry tons of forest residues produced annually in the region.

The goal is for these forest residues to become the foundation of a new multi-feedstock biomass supply chain of blended residues and biomass crops that is available throughout the year. The project focuses on feedstock production, harvest and logistics, optimization, sustainability, system scale-up, education, and outreach. Table 3.2 provides an overview of the opportunities and challenges of BECCS.

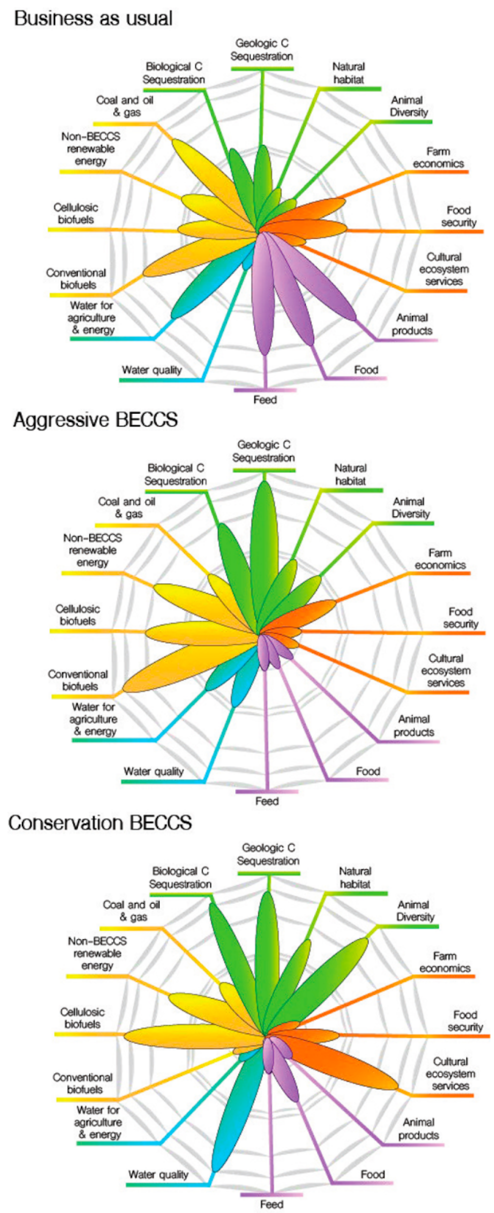


Figure 3.12. Opportunities and Trade-offs among BECCS and the Food, Water, Energy, Biodiversity, and Social Systems Nexus at Regional Scales (Stoy et al., 2018)

Table 3.2. Opportunities and Challenges of Bioenergy with Carbon Capture & Sequestration (BECCS) to Reduce Carbon Dioxide in West Virginia (West Virginia University, 2022)

	Opportunities	**Challenges**
Science and technology	• Biomass sources such as forestry are abundant and largely available for use in carbon removal. • Gasification and pyrolysis are biomass conversion technologies that can produce CO_2 for sequestration. • Policies can increase the amount of biomass available for carbon removal.	• The available amount of biomass is limited, and the location of biomass is static. • Costly treatment infrastructure needs to be installed, operated, and maintained.
Economic prosperity	• Woody biomass fuel supported 246 jobs in West Virginia in 2021. (As comparison, oil provided 3,576 jobs, natural gas 4,141, and coal 12,261).	• Economic and political incentives may be required to increase the speed with which BECCS is implemented if it is to be part of the CDR portfolio.
Environmental & conservation impact	• Planting woody biomass sources on degraded lands can help restore soils and utilize sustainable watering methods to avoid stress on current water systems.	• Biomass production could limit fresh water and decrease water availability if sustainable watering methods are not used. • Monoculture of biomass crops reduces diversity and threatens ecosystem resilience to disturbance, natural disasters, pests, and disease.
Disadvantaged communities	• Biomass production and harvesting could provide additional income for smallholder farmers and new job opportunities in biomass production and harvesting, depending on policy design.	• Economic incentives to encourage biomass production for BECCS could lead farmers to use land previously used for agriculture and lead to rising food prices in disadvantaged communities. In addition, care is needed to ensure that these economic incentives flow to West Virginians rather than absentee landowners.

4: Direct Air Capture

Direct air capture (DAC) is a technological approach to capturing CO_2 directly from the atmosphere using purpose-built machines. This CO_2 can then be used to produce higher-value products (such as synthetic fuels) or permanently stored in deep geological formations, thus achieving carbon dioxide removal.

How Does DAC Work?

Direct air capture technologies use chemical reactions to capture CO_2 from the atmosphere by moving air over a solvent or sorbent array to selectively react with and remove CO_2, while allowing the other components of air (i.e., nitrogen and oxygen) to pass through. Once the CO_2 is removed, energy is required to release the CO_2 from the solvent or sorbent in a concentrated state. This CO_2 is then compressed and is ready for transport, utilization, or storage. Through this process, the solvent/sorbent is regenerated for another cycle of capture.

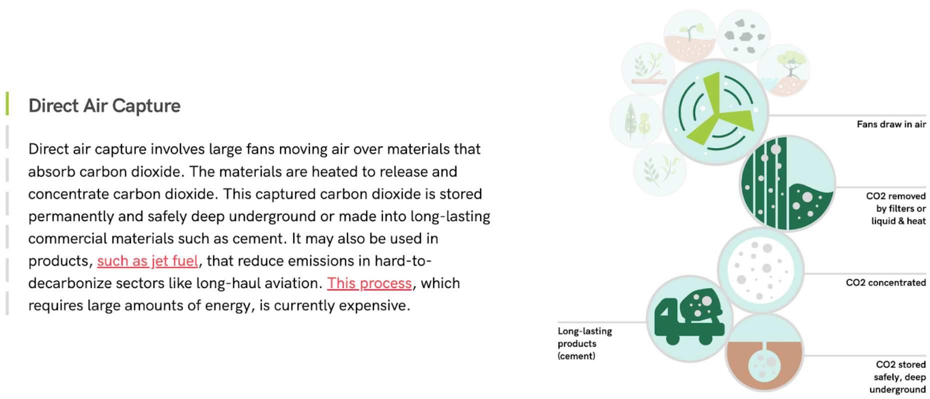


Figure 4.1. How Direct Air Capture Works (adapted from Chan Zuckerberg Initiative, 2022)

There are two primary DAC technologies with different types of energy requirements. Liquid solvent systems require 900C temperatures for solvent regeneration. Current demonstrations of this technology utilize natural gas with carbon capture to produce these high temperatures for regeneration. Solid sorbent systems have lower heat requirements—80 to 120C—which means that solid sorbent systems can utilize the waste heat of other processes. These energy needs will have an impact on the choice of location for a facility. Depending on the source, the energy used to capture the CO_2 may offset volumes captured and be a significant determinant of the cost per ton of CO_2 captured.

Technical Benefits of Implementing DAC in West Virginia

One significant benefit of DAC compared to other CDR options in West Virginia is its relatively low land footprint. For example, the National Academies made the following estimate:

> "If you consider a temperate deciduous forest with a net primary production of 390 km^2 per Mt/y CO2 and an average tree density of 200 per acre, a single tree acts to remove (net), on average, 50 kg CO_2/y; in this sense, a 1 Mt CO_2 direct air capture system does the work of 20 million tree equivalents, or a forest spanning 100,000 acres."

A second significant benefit is that a facility can be located close to suitable storage, eliminating the need for long-distance CO_2 transport.

Technical Challenges of Implementing DAC in West Virginia

The primary challenges of DAC technologies are the energy and scale of equipment needed to capture CO_2 from a dilute stream.

Energy Requirements

Figure 4.2 illustrates the increasing minimum energy requirement for capture as CO_2 streams become increasingly dilute. Since CO_2 in air is highly dilute (~300x more dilute than in the flue gas from a coal-fired power plant, for example), DAC carries higher energy needs and is costlier on a per-kg captured basis than other CO_2 capture technologies and applications.

Costs and energy needs are highly variable, depending on the type of technology used and whether the captured CO_2 is going to be geologically stored or used immediately at low pressure for other products or processes. For geologic storage, CO_2 needs to be highly compressed before it can be injected into deep geological formations. This step increases plant capital costs due to the requirement for additional equipment (such as compressors) and operating expenses to run that equipment.

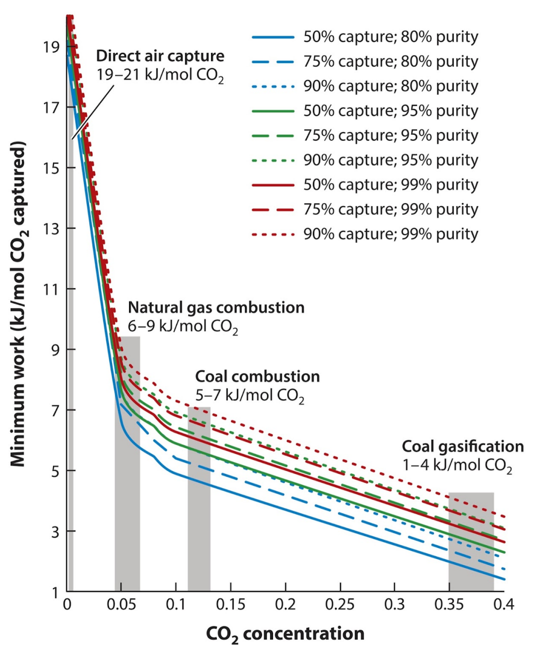


Figure 4.2. Work Requirements for Carbon Capture Based on Concentration, Capture, and Purity (Bui et al, 2018)

Land Requirements

Similar to energy requirements, the land area needed for large-scale DAC deployment depends on the type of system, the scale of the facility, and the source of energy required. In general, liquid solvent systems are larger than solid sorbent plants because of cost advantages specific to building liquid solvent plants. Principally, liquid solvent systems integrate multiple units that scale readily, as opposed to solid sorbent technologies, which benefit from the repetitive use of a single contactor geometry. Generally, solid sorbent plants are smaller and capture less carbon per year.

More significant for land use implications is the impact of CO_2 depletion between DAC capture units, which is highly dependent on technology and local atmospheric conditions, as well as the impact of CO_2 depletion on local land, particularly if arable land is close to the capture facility. The National Academies of Sciences, Engineering, and Medicine (NASEM) finds that this particular risk is not well understood but has significant repercussions on the overall sizing/land use of a capture facility. In the literature, ranges for 1 million ton per year facilities are 0.4km^2 to

1.7km^2 (100-400acre) (Table 4.1). For example, the Oxy Petroleum/1PointFive/Carbon Engineering joint venture in the Permian Basin, Texas, is expected to sequester 500,000T/y on a facility of approximately 100 acres.

Table 4.1. Total Land Areas for Different Combinations of DAC System Type and Energy (World Resources Institute, 2022)

DAC SYSTEM AND ENERGY SOURCE	DAC PLANT AREA (KM^2)	ENERGY SOURCE AREA (KM^2)	TOTAL AREA FOR A 1 MTCO$_2$/YR PLANT (KM^2)
Solvent: NG with CCS	0.4[a]		0.4
Solvent: NG with CCS + solar PV	0.4	7.1	7.5
Solvent: NG with CCS + geothermal	0.4	1.5	1.9
Solvent: NG with CCS + wind	0.4	13.6[c]	14.0
Sorbent: NG with CCS	0.5[b]		0.5
Sorbent: solar PV	0.5	34.2	34.7
Sorbent: geothermal	0.5	7.0	7.5
Sorbent: wind	0.5	65.6[c]	66.0

Notes: NG = Natural gas; CCS = Carbon capture and storage; PV = Photovoltaic; km^2 = square kilometers; MtCO$_2$/yr = Million tonnes of carbon dioxide per year; GtCO$_2$/yr = Billion tonnes of carbon dioxide per year.
[a] Based on Carbon Engineering's plant in development, which uses 100 acres (0.4 km^2) for the DAC plant and energy infrastructure. [b] Assumes colocation of natural gas infrastructure with DAC plant. [c] Within the total land area for a wind farm, only about 1% is directly taken up by turbine bases and access roads; so it can be used for other activities, like grazing

Water Requirements

Similarly, the water usage associated with DAC depends on the system type as well as the ambient temperature and humidity.

For a liquid solvent DAC system, capturing 1T of CO_2 can require between 1,000 and 7,000 liters of water. Water losses come mainly through evaporation, so the relative humidity and temperature of the plant location are the main causes of water loss, with higher losses in hot and dry environments.

Solid sorbent DAC systems in development and production today vary widely in terms of water usage, depending on the sorbent regeneration method. A system that uses steam condensation to regenerate the sorbent may result in water losses to the environment. A typical plant employing this method is estimated to use 1,600 liters of water per ton of CO_2 captured.

Other systems regenerate the sorbent using indirect heating, which allows for minimal water losses. These indirect heating systems are actually net water producers, producing 800-2,000 liters of water per ton of CO_2 captured. In general, DAC systems use water in hot, dry climates but can produce water in cool and humid conditions, such as those commonly encountered in West Virginia.

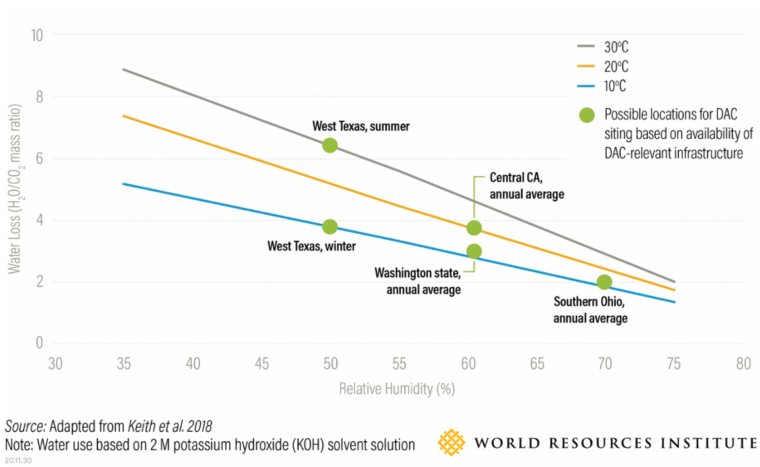


Figure 4.3. Approximating Water Usage in Liquid Solvent DAC Systems Dependent on Meteorological Factors (World Resources Institute, 2021)

Cost Requirements

Table 4.2 shows the ranges of capture cost per ton of CO_2 as estimated by the National Academies. Figure 4.4 provides DAC cost estimates in California from the Lawrence Livermore National Laboratory (LLNL) in its 2020 report, *Getting to Neutral: Options for Negative Carbon Emissions in California*. This policymaker guide uses the LLNL cost estimate in its analysis. (See Appendix G.)

Table 4.2. Estimated Requirements and Costs Associated with Liquid Solvent and Solid Sorbent Direct Air Capture (National Academies of Sciences, Engineering, and Medicine, 2019)

Direct Air Capture System	Energy Source		Energy Required ($GJ/t\ CO_2$)		CO_2 Generated ($Mt/y\ CO_2$)		Net CO_2 Avoided	Capture Cost ($\$/t\ CO_2$)	
	Electric	Thermal	Electric	Thermal	Electric	Thermal	($Mt/y\ CO_2$)	Cap-tured	Net Re-moved[a]
Liquid Solvent	NG	NG	0.74-1.7	7.7-10.7	0.11-0.23	0.47-0.66	0.11-0.42	147-264	199-357
	coal	NG	0.74-1.7	7.7-10.7	0.18-0.38	0.47-0.66	0-0.35	147-264	233-419
	wind	NG	0.74-1.7	7.7-10.7	0.004-0.009	0.47-0.66	0.34-0.53	141-265	156-293
	solar	NG	0.74-1.7	7.7-10.7	0.01-0.03	0.47-0.66	0.31-0.52	145-265	165-294
	nuclear	NG	0.74-1.7	7.7-10.7	0.01-0.02	0.47-0.66	0.32-0.52	154-279	173-310
	solar	H2[b]	11.6-19.8	7.7-10.7	0.01-0.03	0	0.99	317-501	320-506
Solid Sorbent[c]	solar	solar	0.55-1.1	3.4-4.8	0.0004-0.008	0.008-0.01	0.892-0.992	88-228	89-256
	nuclear	nuclear	0.55-1.1	3.4-4.8	0.002-0.004	0.004-0.005	0.91-0.994	88-228	89-250
	solar	NG	0.55-1.1	3.4-4.8	0.0004-0.008	0.22-0.30	0.70-0.78	88-228	113-326
	wind	NG	0.55-1.1	3.4-4.8	0.002-0.003	0.22-0.30	0.70-0.78	88-228	113-326
	NG	NG	0.55-1.1	3.4-4.8	0.07-0.14	0.22-0.30	0.56-0.71	88-228	124-407
	coal	coal	0.55-1.1	3.4-4.8	0.15-0.3	0.32-0.44	0.26-0.53	88-228	166-877

[a] Assuming the use of an oxy-fired kiln to provide heat from natural gas in the calcination process, leading to greater CO_2 production and hence lower cost of net CO_2 removal, using a basis of 1.3 Mt CO_2 for NG/NG, 1.2 Mt CO_2 for coal/NG. (NG = natural gas).
[b] Assuming all hydrogen is produced via electrolysis using near zero-carbon power.
[c] Scenarios range from 2-low to 4-high.

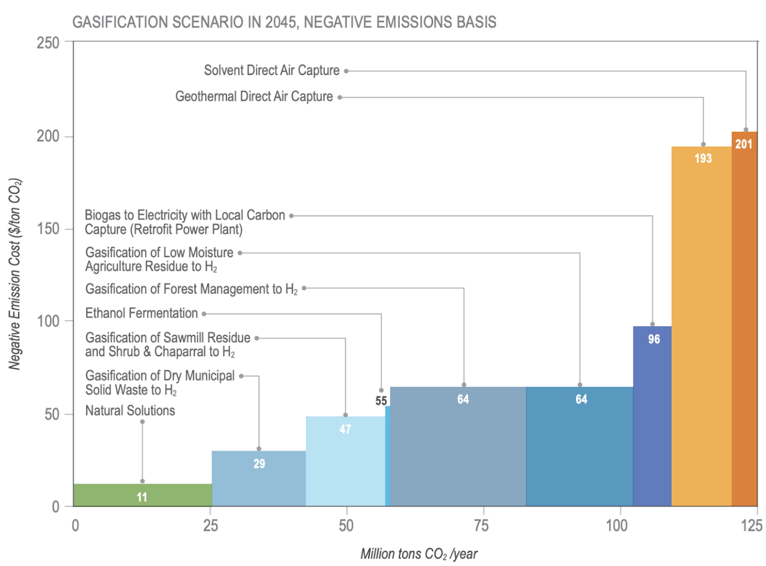
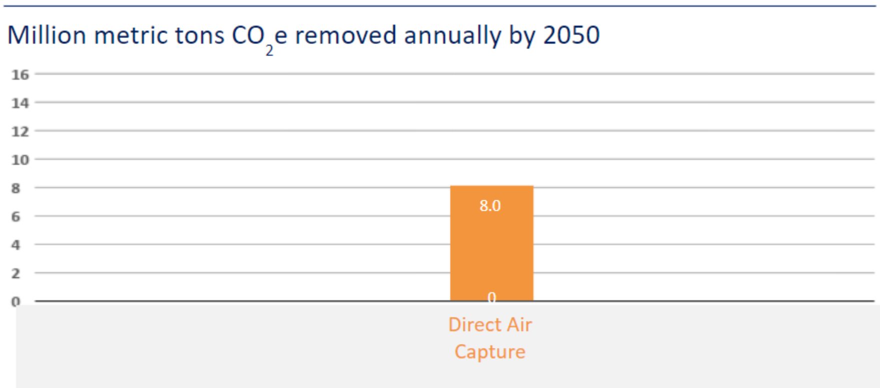


Figure 4.4. Average Costs and Cumulative Quantities for the Lowest-cost Set of Negative Emissions Pathways for California (Lawrence Livermore National Laboratory, 2020)



Note that in the case of both BECCS and DAC, some revenue might be generated from selling the products that result from these processes. In addition, the 45Q carbon oxide sequestration tax credit is already in place, and congressional proposals to modify that tax credit that may subsidize the cost of these options

Figure 4.5. West Virginia's Direct Air Capture Sequestration Potential in Southern West Virginia (West Virginia University, 2022)

Case Study: Direct Air Capture Deployment in West Virginia

Although technically DAC can be located anywhere in West Virginia, realistically, it is best located near potential CO_2 storage locations. This avoids the financial and social challenges associated with transporting the CO_2 to industrial locations where it can be utilized. In addition, placement of DAC near former coal sites in West Virginia can potentially provide a source of employment for residents of these disadvantaged communities, where unemployment rates are high. Figure 4.6 provides unemployment rates in West Virginia. Some of the counties with the highest rates and with locations near possible CO_2 storage sites are in southern West Virginia. They are the West Virginia counties used in the Direct Air Capture/Carbon Sequestration case study below: Boone, Logan, Mingo, Raleigh, and Wyoming. In this case study, we evaluate the potential for DAC deployment and potential storage volumes from deployment in these areas (details are provided in Appendix G).

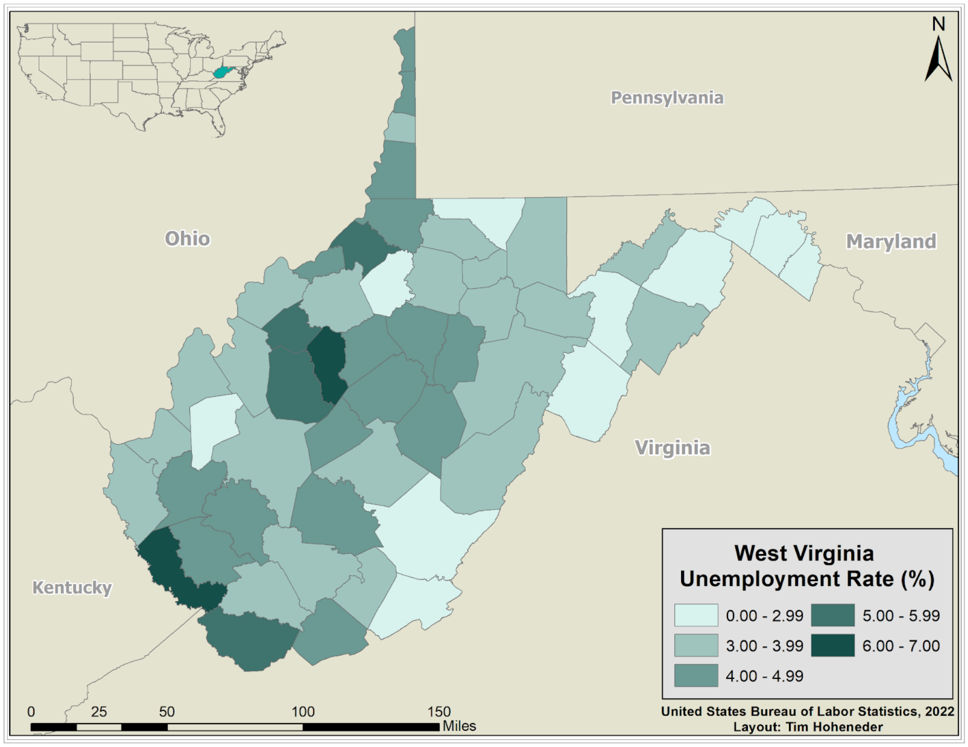


Figure 4.6. Unemployment Rates, by County, West Virginia, November 2021 (U.S. Bureau of Labor Statistics, 2022)

Overall, we identified 66 potential DAC/carbon capture sites with >100A footprints in these five counties, overlying potential storage reservoirs of 30MT. While further analysis would be required, these details highlight the strong potential for the deployment of DAC facilities in the southern coalfields. Table 4.3 identifies the number of mine sites by acres available.

Table 4.3. Mine Sites Overlying 30MT Storage (West Virginia University, 2022)

Acres	Number of Mine Sites
100+	66
400+	15
800+	5
1,200+	2
Average Acres/Site	426.69

Figure 4.7 provides information on the maximum amount of DAC that can occur in southern West Virginia near potential storage sites. This estimate is based on our understanding of the potential to store carbon as of today, which is approximately 248 million metric tons over 30 years (until 2050), or about 8 million metric tons per year. While we have some confidence in these estimates, they may certainly change (for better or worse) as we learn more.

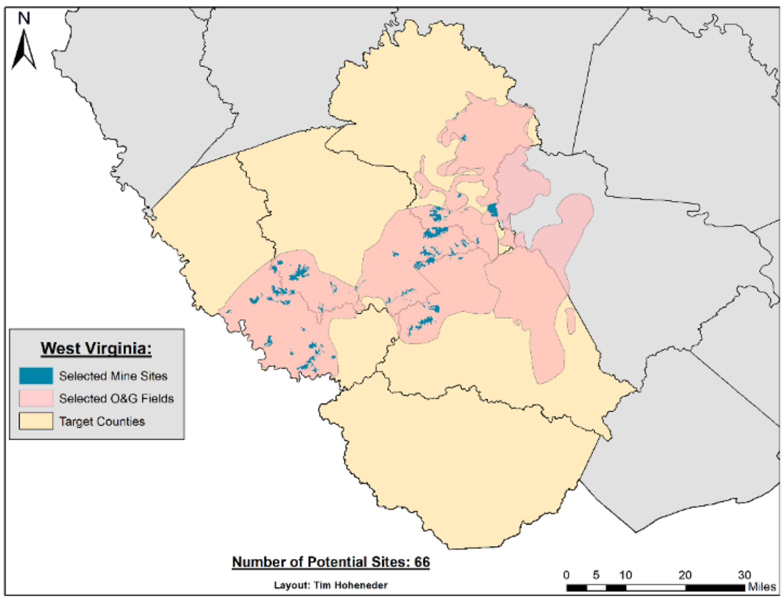


Figure 4.7. Map of Potential Direct Air Capture Sites in Southern West Virginia Based on Potential for CO_2 Storage (West Virginia University, 2022)

Figure 4.8 overlays the location of the 66 sites relative to the disadvantaged communities and the people of color in these targeted counties. Of course, while there are potential employment opportunities, there are also potential risks associated with DAC/carbon sequestration. Care must be taken to ensure that these communities benefit from DAC investments and that they are not adversely affected. Chapter 6 provides policy options and recommendations to avoid challenges that may arise as deployment of this technology advances globally.

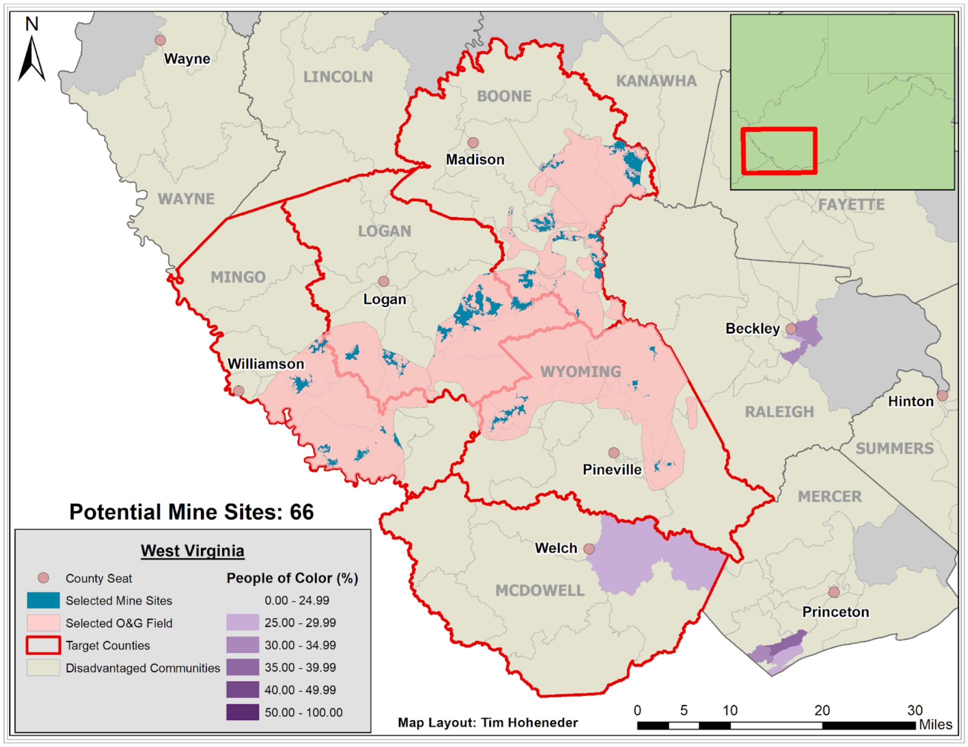


Figure 4.8. Map of Potential Direct Air Capture Sites in Southern West Virginia Based on Potential for CO_2 Storage with Proximity to Disadvantaged Communities (Tan) and People of Color (Purple) (West Virginia University, 2022). Data on disadvantaged communities and people of colors from based on data from White House Council on Environmental Quality (CEQ) Climate and Economic Justice Screening Tool, version 1.0, 2022.

Table 4.4 estimates the potential annual total economic impact in the region: $0-2,663 million in economic output and 0-6,402 total jobs per year for DAC (see Appendix J for details), while Table 4.5 identifies both the potential opportunities and challenges associated with deployment in the region.

Table 4.4. Annual Economic Impact of Direct Air Capture in West Virginia (West Virginia University, 2022)

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	0–1,608	0–1,055	0–2,663
Employment (jobs)	0–1,740	0–4,662	0–6,402
Labor Income ($, millions)	0–254	0–269	0–523
Total Taxes ($, millions)	0–27	0–29	0–56

Table 4.5. Opportunities and Challenges of Direct Air Capture (DAC) to Reduce Carbon Dioxide in West Virginia (West Virginia University, 2022)

	Opportunities	Challenges
Science and technology	• DAC has been considered one of the most effective carbon capture technologies, with rapid deployment being technically feasible.	• Energy requirements for DAC technology have been widely cited as one of the toughest challenges to the rapid deployment of DAC across the states. Energy costs and overall CO_2 benefit are uncertain, depending on which energy source is being used. • Storage capacity is key for DAC technology to be effective in a given region, with low storage capacity being detrimental to the CDR potential (Marcucci et al. 2017).
Economic prosperity	• If DAC reaches full scale, workers in key trades will also see a surge in demand. A typical 1-megaton capacity DAC plant can generate roughly 3,500 jobs across the sectors in the DAC supply chain.	• New federal policy is required to drive initial deployment of DAC and the related employment opportunities because early-stage costs are higher than existing revenue opportunities.
Environmental & conservation impact	• A life cycle assessment conducted on two existing Climeworks DAC facilities with low-carbon energy sources found that they	• The primary environmental concerns are based on effective storage site construction methods that will not negatively impact the local environment.

	achieved carbon capture efficiencies of 85.4% and 93.1%.	• There are outstanding questions about the overall net removal of CO_2 using DAC when considering powering DAC facilities (with low-carbon/renewable energy sources).
Disadvantaged communities	• One incentive to implement DAC technology in especially viable locations, where geologic storage can be achieved without much transportation and pipeline issues, is the potential for monetary gains and rebates for people living in the communities surrounding these facilities.	• Public acceptance of new technologies like DAC is uncertain. Some may be concerned that their community is expected to accept the risk of a relatively new technology while the benefits accrue to those who own property and live elsewhere.

Summary

The characteristics of current DAC systems make them attractive options for West Virginia. While renewable energy generation is relatively limited in the state, abundant natural gas, as well as potentials for geothermal energy, provide options for thermal energy to power DAC systems. The flexibility in siting allows for the targeting of deployment to areas that have storage available while minimizing infrastructure and CO_2 transport costs. These same locations in West Virginia are former coal communities and face the greatest economic challenges in the state, so deployment in these regions can potentially lead to job creation and other economic opportunities. Care must be taken, however, as this technology develops, to avoid environmental and safety concerns that we cannot foresee at this time. This issue is discussed in Chapter 6.

5: Carbon Sequestration, Storage, and Utilization

Some CDR options, including DAC and BECCS, require that the CO_2 be utilized or stored in order to mitigate climate change. After capture, the CO_2 is compressed and deeply chilled so that it becomes a fluid. This fluid can then be transported through pipelines, ships, trains, and trucks so it can be turned into products or stored in deep geological formations thousands of feet below the surface. Potential long-term CO_2 geological storage options include unmineable coal seams, depleted oil and gas reservoirs, saline formations, and other options (Figure 5.1).

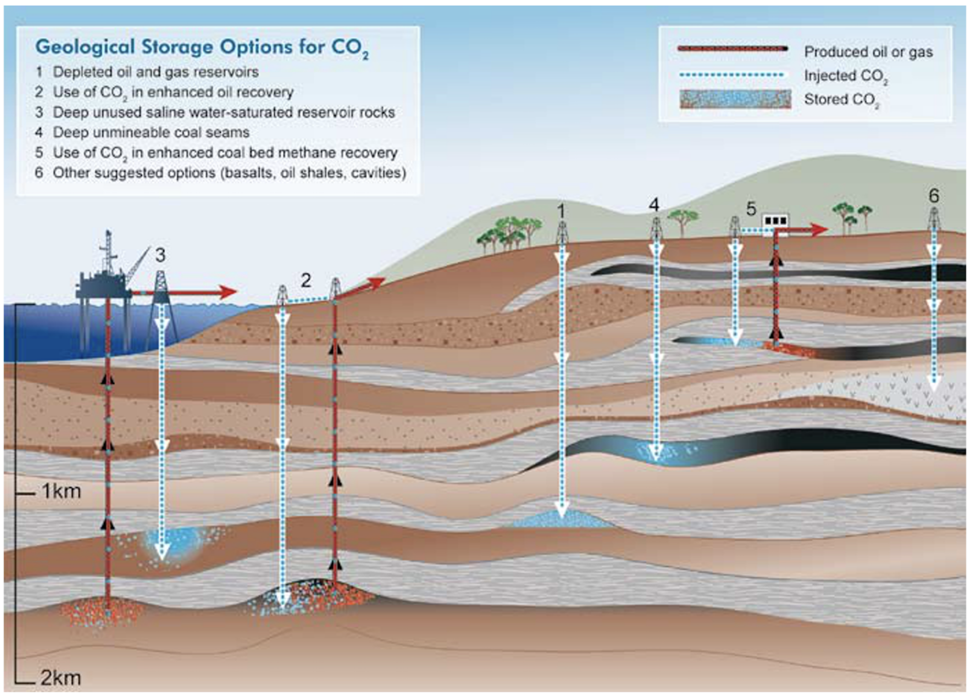


Figure 5.1: Geological Options for Storing CO_2 (IPCC, 2018)

While in some geographic locations the CO_2 would need to be transported long distances, in West Virginia, there are a number of options available for permanent geological storage, such as depleted oil and gas reservoirs and unmineable coal seams (illustrated in Figure 5.1). The potential availability of these storage options may offer West Virginia an advantage over other regions. It should be noted, however, that CO_2 storage locations are valuable for other important services as well (e.g., hydrogen storage), so utilization of them will be competitive.

Further, ensuring that a specific site will work for permanent CO_2 storage is challenging and requires technical assessments, data collection, and permitting. The basic requirements that a geologic formation must meet for successful subsurface CO_2 storage are to (1) have a high storage capacity; (2) be sealed so that the injected CO_2 cannot escape; and (3) be more than 800 m (critical point of CO_2) in depth. From this high-level theoretical assessment, a number of sites are identified for the second level assessment, which includes publically available well data. Sites that pass this test then may require even more data as required by the EPA for permitting. This step may require drilling a new well at the proposed location.

Carbon Sequestration and Storage

Table 5.1 provides estimates of how much CO_2 storage is available in West Virginia from the National Energy Technology Laboratory (NETL) atlas. These estimates, however, are high-level, preliminary estimates that may be optimistic. A more rigorous assessment has been conducted by the U.S. Geological Survey (USGS), but these are not state specific. As noted by the USGS, "The goal of this project was to conduct an initial assessment of storage capacity on a regional basis, and results are not intended for use in the evaluation of specific sites for potential CO2 storage."

Table 5.1. Storage Capacity of Different Geological Formations in West Virginia Based on Estimates (NETL Carbon Storage Atlas V Edition)

	Storage Capacity in Billion Metric Tons		
	Low	Medium	High
Oil and Natural Gas Reservoirs	5.93	9.84	18.05
Unmineable Coal Seams	0.37	0.37	0.37
Saline Formations	11.9	11.9	11.9
TOTAL STORAGE RESOURCE	17.49	21.40	29.61

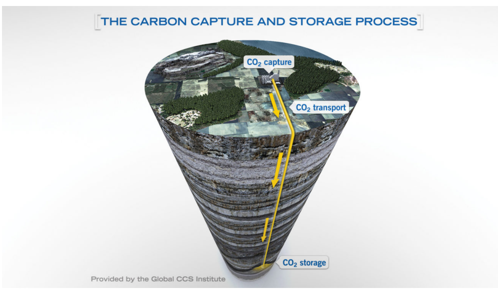
The WVU team believes there is a tremendous need for further analysis and targeted location assessments. The DOE's CarbonSAFE Initiative is attempting to fill that knowledge gap by funding and developing "projects focused on ensuring carbon storage complexes will be ready for integrated Carbon Capture, Utilization, and Storage (CCUS) system deployment in the 2025-2030 timeframe." Currently, however, there are no projects in West Virginia.

Identifying the feasibility of these storage options in West Virginia is not an easy task. Not every location that might be used for BECCS or DAC has an injection well that can be used to inject and store carbon. In particular, the U.S. Environmental Protection Agency (EPA) does not allow injection if the underground water is not salty enough—that is, it must have more than 10,000 mg/L of total dissolved solids. As noted by the NETL, sites must have the following characteristics as well as meet EPA permitting requirements:

- **Storage Resource** – A storage site needs to have sufficient storage resource (space) to contain large amounts (millions of metric tons) of compressed CO_2. The storage resource is a fraction of the pore volume of porous and permeable sedimentary formations available for storage (Box 5.1).

- **Injectivity** – This refers to the rate at which CO_2 can be injected into the subsurface. Injectivity of the CO_2 is directly related to the permeability of the formation. The permeability of a formation is a measure of the resistance to fluid flow through it. If fluid can easily pass through the formation, it has "high permeability."
- **Integrity** – This refers to the ability to confine CO_2 safely within a predetermined volume without a breach from the storage complex. A storage complex must have one or more confining zones that seal above the injected formation that are intact and do not have leakage pathways.
- **Depth** – The CO_2 storage zone needs to be located at a sufficient depth and pressure so that CO_2 can be injected as a supercritical fluid. Supercritical CO_2 is dense and behaves more like a liquid than a gas, allowing for storage of higher concentrations of CO_2 by volume.

Box 5.1. What is Geological Storage, and Who Owns Rights to Pore Space?



As described by the Global CCS Institute, an "international think tank whose mission is to accelerate the deployment of carbon capture and storage (CCS)":

"Geological storage involves injecting captured CO_2 into rock formations (not caverns) - called a storage formation - typically underground at depths of more than 1 km, thereby permanently removing it from the atmosphere. Storage formations are typically associated with the following characteristics:

- Pores - millimeter-sized voids that provide the capacity to store the CO_2
- Permeability - a geologic feature wherein the pores in a rock are sufficiently connected. Permeability enables the injection of CO_2 at the required rate, allowing the CO_2 to move throughout the formation.
- Permanence - a storage formation must include an extensive cap rock, or barrier, around the formation which helps ensure the CO_2 is contained permanently."

In March 2022, West Virginia's Governor signed legislation into law to "establish requirements for carbon dioxide sequestration." As summarized by the Charleston Gazette-Mail, the act would:

- Require a permit to operate a CO_2 storage site to drill injection wells and sequester carbon dioxide at specified site;
- Require a permit application fee, determined by the West Virginia Department of Environmental Protections (WVDEP), that would be deposited into a CO_2 storage facility administrative fund;
- Require WVDEP to issue a permit only if those owning or leasing minerals would not be adversely effected or addressed in a written agreement between mineral owners,

lessees, and the storage operator;

- Require the storage operator to
    - Make a “good faith effort” to get the consent of storage reservoir pore space owners;
    - Obtain written consent of people who own at least 75% of the storage reservoir’s pore space;
    - Identify remaining pore space owners through West Virginia’s Oil and Gas Conservation Commission;
    - Assess migration of injected CO_2 ;
    - Compensate nonconsenting pore space owners;
    - Be liable for any damage CO_2 might cause until WVDEP issues a certificate of completion.

- Require WVDEP to
    - Rule on permit applications within one year;
    - Wait at least 10 years to issue completion certificate;
    - Transfer pore space ownership back to pore space owners after completion certificate is issued;
    - Be liable for stored CO_2 after completion certificate is issued, defend pore space and source owners against claims using funds from the CO2 facility trust fund.

Using Oil and Gas Depleted Fields for CO_2 Sequestration

Depleted oil and gas fields can be ideal targets for CO_2 sequestration because typically

1) the reservoirs are well characterized in terms of depth, size, and resource storage capacity,

2) reservoirs have well-defined seals that will prevent CO_2 leakage from the reservoir into which it is injected, and

3) the process can produce value-added residual oil and gas that will be carbon negative.

The down side of these fields is that they may have numerous known or unknown artificial penetrations and wells of inadequate completion quality, and these may act as conduits for CO_2 leakage. This can be a manageable issue depending on the field. Conversely, deep saline formations may be relatively more free of such penetrations, but—exactly due to this lack of exploration—less data is typically available about their rock properties and their suitability for storage.

West Virginia has a long history of oil and gas development going back to the 19th century. During the last decade, rapid shale gas development in the northern part of the state has also opened up the possibility of utilizing these hydraulically fractured shale reservoirs as potential target reservoirs for CO_2 sequestration. The location, extent, and approximate sequestration potential of all the oil and gas fields in the state, along with the power plant locations symbolized by their 2013 CO_2 emissions, are depicted in Figure 5.2.

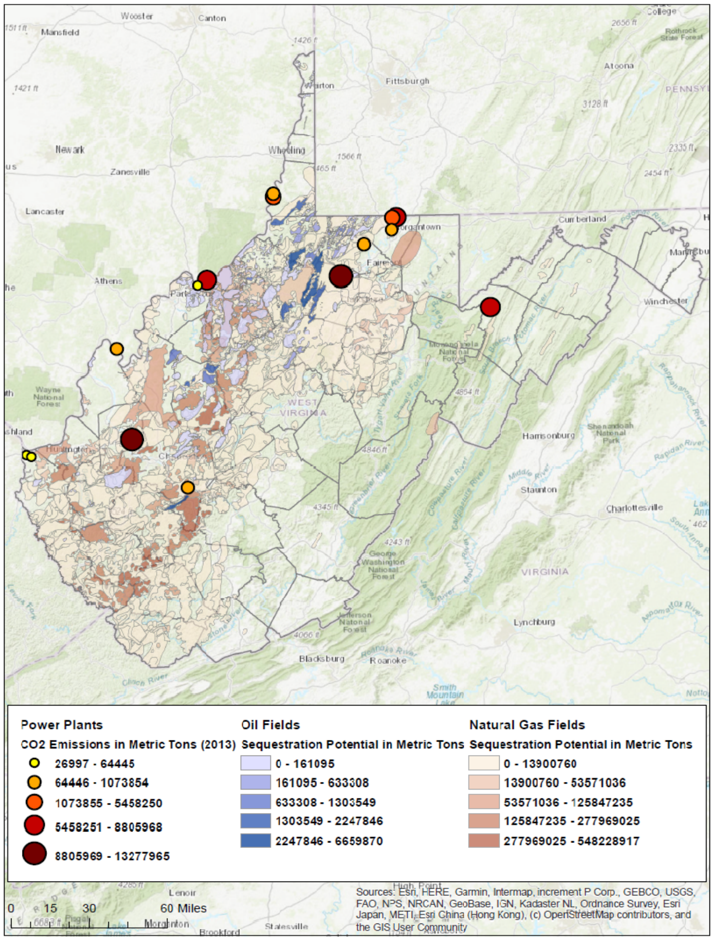


Figure 5.2. Major Oil and Gas Fields in West Virginia, with Approximate CO_2 Storage Potential (West Virginia University, 2022) *This map shows the spatial extent of all the major oil and gas fields in the state along with their approximate CO_2 storage (sequestration) potential. This map also shows the location of major power plants in relation to these oil and gas fields. The size of each power plant is proportional to its total CO_2 emission in 2013.*

Identifying Possible Carbon Storage Locations in West Virginia

To develop CO_2 sequestration projects and business opportunities in West Virginia, it is necessary to identify a demonstration site based on a rating criterion that includes

- proximity to power plants (if we are targeting CDR from point source emissions);
- availability of deep oil and gas reservoirs (for permanent CO_2 storage) or abandoned mine lands/gas storage fields (for temporary CO_2 storage and utilization);
- proximity to the available infrastructure of transport, roads, pipes, and wells; and
- socioeconomic impact on the fossil fuel based rural communities.

After the site has been selected, the remaining challenges that will need to be addressed are

1) conducting a comprehensive geological, geochemical, and geomechanical characterization of formations in which CO_2 will be injected;
2) obtaining required permits;
3) maintaining the supply of CO_2;
4) assessing the economic viability of sequestration operation; and
5) securing public confidence in this new technology.

Additional information on this topic is available in Appendix F.

Carbon Utilization

As a result, CO_2 might need to be transported to another location so it can be stored or turned into a product. The latter process is called CO_2 utilization and is a very active field of research and development. Some of the most promising technologies, based on market research, are

- building materials (concrete, carbonate aggregates);
- chemical Intermediates (methanol, formic acid, syngas);
- fuels (liquid fuels, methane); and
- polymers (polyols and polycarbonates).

The full range of options is shown in Figure 5.3. Figure 5.4 provides information on the market value of each. When considering how CO_2 might meet needs throughout West Virginia, the most significant potential is likely the mineralization of CO_2 to produce concrete, cement, and building materials. The advantages of this option are discussed in Figure 5.5.

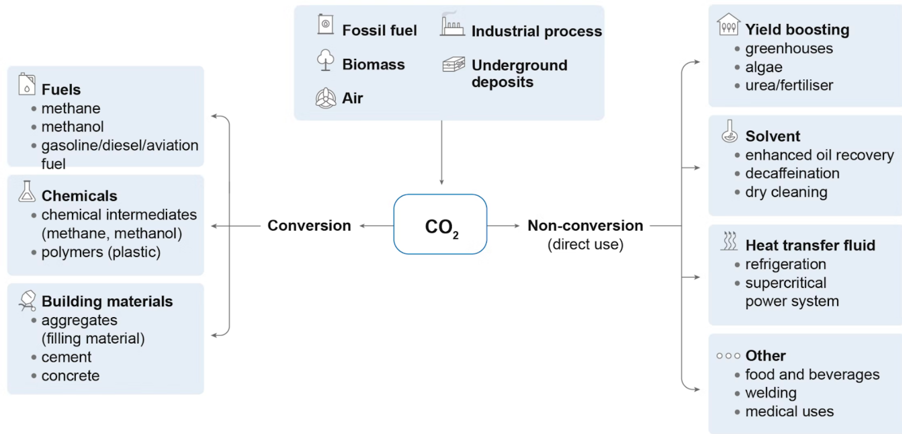


Figure 5.3. Simple Classification of Pathways for CO_2 Use (International Energy Agency, 2019)

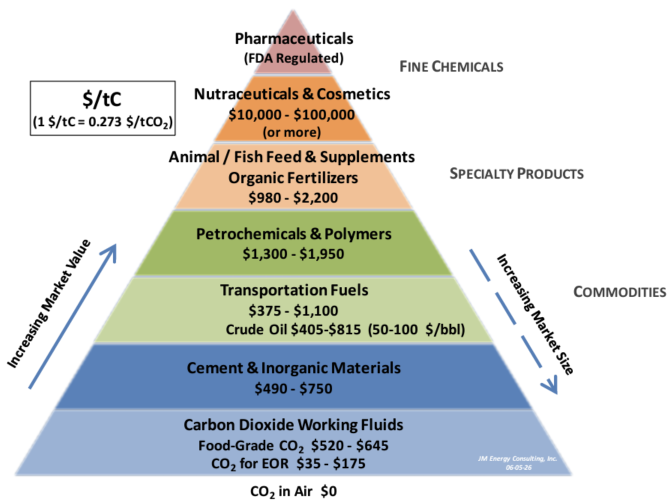


Figure 5.4. Market Value of Various Carbon-Based Goods and Services (White House Council on Environmental Quality, 2021)

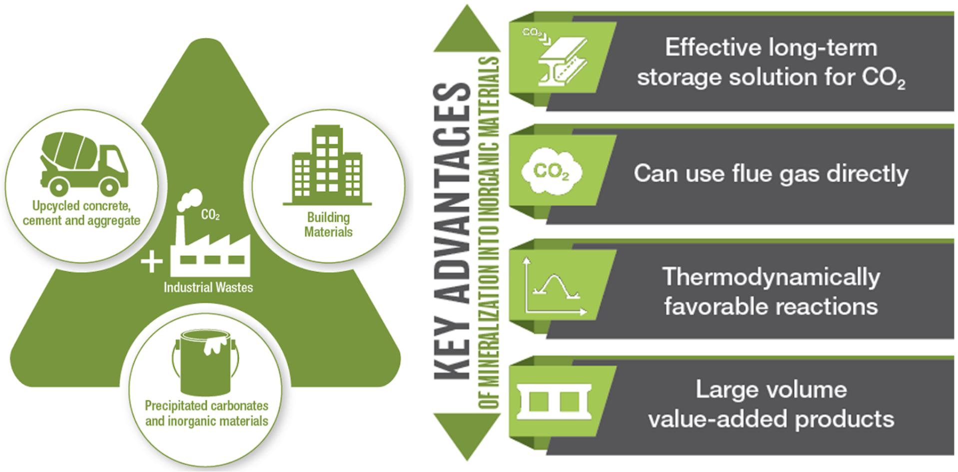


Figure 5.5. Mineralization of CO_2 into Inorganic Materials (NETL, 2022)

The opportunities and challenges of carbon sequestration, storage, and utilization are discussed in Table 5.2

Table 5.2. Potential Opportunities and Challenges of Carbon Sequestration, Storage, and Utilization to Reduce Carbon Dioxide in West Virginia (West Virginia University, 2022)

	Opportunities	**Challenges**
Science and technology	**Carbon Storage** • Carbon storage is a proven, technology that can accommodate large volumes and requires minimal land use/surface footprint. • The use of depleted/declined Marcellus wells could provide a ready pathway for early deployment, reducing the project cost through use of existing wells (Bielicki et al., 2018).	• As is the case with other carbon storage options, such as deep saline, additional research is needed to determine if shale infrastructure (such as Marcellus wells) is an option for carbon storage. In addition, permission would be needed from the EPA to allow these wells to receive its Class VI well designation, which allows the storage of CO_2.

	• The combination of DAC with storage would allow for the decoupling of CO_2 production (and thus transport) and storage, allowing for targeting of storage reservoirs and deployment in more desirable locations (based on economic or other characteristics).	
	Carbon Utilization • There is enormous interest in carbon-to-products, ranging from biologic type processes (including forests, algae, and conversion of those feeds to fuels and other products) to direct chemical conversion to fuels, chemicals, plastics, and solid carbons. Recent estimates project 13% annual growth rates in CO_2 product markets (Zhang et al., 2020).	• While the value of these products and markets is significant, the volumes of CO_2 utilized are relatively low compared to global CO_2 emissions. Long-term potential is estimated at 1-2GT/y, compared to current emissions in excess of 30GT/y (Zhang et al., 2020).
Economic prosperity	• Injecting CO_2 into unmineable coal seams can enhance coalbed methane recovery, potentially offsetting the costs of the CCS operation. • Some benefits of using depleted oil and gas reservoirs for CO_2 storage are that the formations are already extensively studied and well characterized; both the surface and underground infrastructure is already in place; and the process can result in enhanced oil and gas recovery—all of which can offset the costs of CCS	• The rates of chemical reactions between CO_2 and fluids and minerals that could potentially affect reservoir integrity are not well constrained, leaving room for some uncertainty regarding long-term storage in oil and gas reservoirs.

	operations.	
Environmental & conservation impact	• In March 2022, West Virginia put into place a law that requires carbon capture operators to obtain permits from the WVDEP and establishes criteria for issuing those permits. Facility operators are also required to obtain permission from 75% of the pore space owners. • Since the locations and storage capacity of some potential geologic reservoirs are already known, DAC or other capture technologies can be co-located at the sites, eliminating the need to build infrastructure to transport the CO_2 to the storage locations, thus minimizing impacts to land and environment.	• CCS could potentially affect groundwater chemistry and drinking water sourced from local groundwater wells, which may require risk assessment and management.
Disadvantaged communities	• Possible locations for CO_2 storage are often in locations of past oil, gas, or coal activities, where communities have lost jobs due to the transition to alternative energy sources. Jobs and community benefits may result from investments in CO_2 storage in these regions.	• Past CDR activities in the global south have led to “inadequate payments, loss of local control over natural resources, loss of ability to use their land for other livelihood purposes.”

6: Findings, Policy Options, and Recommendations

Throughout this policymaker guide, we have answered the following questions:

- What are potential scientific and technological opportunities and challenges to the removal and storage of CO_2 from the atmosphere in West Virginia?
- How could the effective and efficient removal and storage of CO_2 from the atmosphere enhance economic prosperity and job creation in West Virginia?
- What are potential new ecological, conservation, and environmental opportunities and challenges to the removal and storage of CO_2 from the atmosphere in West Virginia?
- What are the associated opportunities, challenges, risks, and empowerment potential for traditionally socio-economically disadvantaged communities, including communities of color and those located in former coalfields?
- What actions, if any, should national, state, and local West Virginia policymakers take to enhance the removal and storage of CO_2 from the atmosphere to reduce climate variation, increase economic opportunities, and create jobs for West Virginians?

In this section, we summarize the findings, policy options, and recommendations that respond to these questions. They address the following goals:

- ➢ Create carbon reduction opportunities in West Virginia
- ➢ Restore carbon into West Virginia's natural resources
- ➢ Benefit West Virginia’s economic prosperity and create jobs for West Virginians
- ➢ Open CDR opportunities while protecting West Virginia’s ecology, conservation, and environment
- ➢ Nurture West Virginia’s disadvantaged communities

Create Carbon Reduction Opportunities in West Virginia

Finding 1: West Virginia has the most scientific and technological carbon reduction potential for CDR options using natural methods (such as forests, agriculture, wetlands, and forest products, which can be implemented immediately) as well as bioenergy with carbon capture and sequestration (BECCS) (which can take varying amounts of time depending on the technology chosen) and direct air capture (DAC) (which requires additional time for the development of appropriate carbon sequestration pathways). Carbon mineralization is not an option due to the state’s geology. Whatever CDR options are chosen, care should be taken to establish appropriate standards and verification processes.

On a near-term basis, the CDR options with the most potential in West Virginia are natural methods including forest, crops, soil, and freshwater inland wetland management. The primary focus should be on family forest owners, as they may need financial and other support to manage their land. An example of active non-profit organizations working on these issues are The Nature Conservancy and American Forest Foundation, who are managing the Family Forest Carbon Program.

Similarly, West Virginia should explore the potential for using engineered wood products to store carbon as part of the building construction process. This could be a boon for the forest products industry if wood products were used instead of alternatives that do not store carbon. If forests are managed appropriately, incentivizing carbon storage in wood products can offset the higher cost of building with wood, ultimately reducing atmospheric carbon dioxide levels and supporting the forest product industry that is important to West Virginia.

On a medium-term basis, BECCS has the most potential. Currently, there are no BECCS facilities in West Virginia, though there are bioenergy facilities and efforts to increase that energy source, including the MASBio project. As a result, revenue opportunities are lost that could otherwise benefit local communities. Policy actions could be taken today to encourage the construction of these facilities in appropriate regions of West Virginia.

On a long-term basis, DAC has the most CO_2 removal potential. The technology, however, needs further research and development before full implementation. In this case, a demonstration project to understand its potential in different regions of West Virginia would be most useful.

Carbon mineralization (ex-situ and in-situ) is not an option in West Virginia. This is because the geology in West Virginia is not suitable to support this method.

Although West Virginia's potential for participation in carbon markets is high given its natural resources, West Virginians cannot benefit without additional organization due to the large number of small landowners. In addition, neutral state agencies should provide landowners with a complete picture of the economic potential and possible future land use restrictions involved with engaging in the carbon credit market. Active engagement supported by policymakers is necessary to facilitate cooperative efforts; this would involve engaging small landowners, providing them with plans to make participation easier, and providing information on the wetlands on their lands.

This finding leads to the following policy options:

Policy Option 1-1: Work with federal agencies (U.S. Department of Energy (DOE) and U.S. Department of Agriculture (USDA)) and leading nongovernmental organizations to develop appropriate standards for net carbon accounting of stored and sequestered carbon to maximize the eligibility to sell West Virginia nature-based carbon as offsets.

Policy Option 1-2: The USDA, working with the DOE, should request to fund a study by the National Academies of Science, Engineering, and Medicine (NASEM) to determine the optimal harvest cycle for maximizing the carbon removal potential by forests and forest products. The study should also consider ecological factors (e.g., the role trees play in mitigating flooding), social factors (e.g., landowner goals), and economic factors (e.g., life cycle analysis of wood products and impact on the forest products industry).

Restore Carbon Into West Virginia's Natural Resources

Finding 2: The chief challenge for the implementation of BECCS and DAC options is developing a better understanding of the ability to store CO_2 in West Virginia. There are many possible locations, but site-specific analysis and demonstration projects are needed to assess the technical viability of carbon storage options for BECCS and DAC.

Site-specific analysis and demonstration projects are needed to assess the technical viability of these options. Both BECCS and DAC need locations where the captured carbon can be stored. West Virginia has options to store CO_2 in oil and natural gas reservoirs, unmineable coal seams, and saline formations. Alternatively, captured CO_2 can be utilized to manufacture concrete or chemicals requiring industry cooperation. For BECCS, storage options include gasification, combustion, fast pyrolysis, hydrothermal liquefaction, and biogas utilization. Other options include utilizing the carbon in the production of fuels or chemicals, using it for enhanced oil recovery, and other possibilities, some of which are still being researched.

The WVU team has identified a number of potential locations for DAC and carbon sequestration based on the data available (see Appendix G). Each site is different, however, and non-geological factors, such as local infrastructure, will also play a role in determining ideal locations. Technical studies and demonstration projects are thus needed before widespread implementation can begin.

This finding leads to the following policy options:

Policy Option 2-1: Incorporate BECCS into the existing U.S. Renewable Fuel Standard.

Policy Option 2-2: Fund a study that examines both community and technical opportunities and challenges to identify suitable locations for DAC demonstration projects in West Virginia. This study, perhaps funded by the new DOE Office of Clean Energy Demonstrations, should include financial support for the creation and maintenance of community infrastructure (e.g., roadways, water, noise prevention) that might be impacted by DAC development and operations.

Benefit West Virginia's Economic Prosperity and Create Jobs for West Virginians

Finding 3: CDR has the potential to generate economic prosperity and job creation, particularly in West Virginia's coal communities and other rural communities. The natural options are in rural areas and abandoned mine lands, while potential carbon storage sites for DAC are near the hardest-hit coal communities in southern West Virginia as well as oil and gas reservoirs throughout the state.

Much of West Virginia is rural and has the potential to participate in CDR activities—involving reforestation, improved forest management, forest products, and bioenergy—that can provide economic benefits and job creation for the region.

Southern West Virginia is the most economically challenged area of the state, but it also has some of the greatest potential for CDR activities. If CDR activities are implemented, they could provide potential economic benefits in this region of the state. Two examples of this potential are growing trees on abandoned mine lands (approximately 200,000 acres) and locating DAC facilities near CO_2 storage (66 possible sites; see Appendix D) in deep oil and gas reservoirs (for permanent CO_2 storage) or abandoned mine lands/gas storage fields (for temporary CO_2 storage and utilization).

There are federal funds available from the Abandoned Mine Reclamation Fund as well as an additional $11.3 billion emergency appropriation for AML in the Infrastructure Investment and Jobs Act that West Virginia could use to fund reforestation activities on AML. For DAC, the 45Q tax credit provides financial incentives for DAC facilities (as well as point source carbon capture), which were increased in the 2022 Inflation Reduction Act.

Table 6.1 provides an overview of the CO_2 removal potential and the related financial investment. Tables 6.2-6.4 describe the potential job creation based on those financial investments. Details of all the analyses reported in these tables is provided in the appendices. There is considerable uncertainty and variability in both the CO_2 removal and cost estimates.

Table 6.1. Carbon Dioxide Removal (CDR) Potential in West Virginia

CDR Method	**Potential CO2 Removal** **(Million metric tons CO2e/year by 2050)**	**Cost Estimate**[1] **($/ton CO2e) 2025-2045**	**Annual Investment Estimate** **(million dollars/year)**[2]
Natural (forestland, crops, soil, and freshwater inland wetland management)	1.1-8.8	11-11	$12-97
Bioenergy with Carbon Capture (BECCS; new build)	2.7-13.2	120-96	$324-1267
Direct Air Capture (DAC)	0-8	243-201	$0-1608

Notes:

[1] Cost estimates are from the Lawrence Livermore National Laboratory Report (LLNL) Getting to Neutral: Options for Negative Carbon Emissions in California (2020). The first number is the projected cost in 2025 and the second number is the projected cost in 2045. Cost is expected to decrease over time due to technological learning for BECCS and DAC, while there is sufficient knowledge about natural methods based on the long-term implementation of this method. The DAC option assumes that natural gas supplies the power as opposed to renewable energy options such as wind or solar. Note, however, that the WVU team believes there is considerable uncertainty and variability in both the CO_2 removal and cost estimates.

[2] The annual investment estimate is determined by multiplying the lower-bound estimates for both CO_2 removal and cost. Similarly, the upper-bound estimate is determined by multiplying the upper-bound CO_2 removal by the upper-bound cost estimate. Note that in the case of both BECCS and DAC, some revenue might be generated from selling the products that result

from these processes. In addition, the [45Q carbon oxide sequestration tax credit] is already in place and was updated in 2022.

Table 6.2. Annual Economic Impact of Natural Carbon Sequestration Efforts in West Virginia (West Virginia University, 2022)

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	12.2 – 54.6	6.0 – 26.7	18.2 – 81.3
Employment (jobs)	126 – 561	74 – 331	200 – 892
Labor Income ($, millions)	7.8 – 34.8	2.7 – 12.0	10.5 – 46.9
Total Taxes ($, millions)	0.7 – 3.2	0.3 – 1.1	1.0 – 4.3

Note: Tax Revenue impact includes sales, personal income, property, and corporation net income taxes.

Table 6.3. Annual Economic Impact of Biomass to Electricity Spending in West Virginia (West Virginia University, 2022)

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	324 – 859	181 – 481	505 – 1,339
Employment (jobs)	205 – 543	601 – 1,592	806 – 2,135
Labor Income ($, millions)	30 – 80	42 – 111	72 – 191
Total Taxes ($, millions)	5 – 13	5 – 12	10 – 26

Note: Tax Revenue impact includes sales, personal income, property, and corporation net income taxes.

Table 6.4. Annual Economic Impact of Biomass to Fuels Spending in West Virginia (West Virginia University, 2022)

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	99–512	36–185	135–697
Employment (jobs)	68–354	227–1,171	295–1,525
Labor Income ($, millions)	10–50	10–52	20–102
Total Taxes ($, millions)	1–5	1–5	2–10

Table 6.5. Annual Economic Impact of Direct Air Capture Spending in West Virginia (West Virginia University, 2022)

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	0–1,608	0–1,055	0–2,663
Employment (jobs)	0–1,740	0–4,662	0–6,402
Labor Income ($, millions)	0–254	0–269	0–523
Total Taxes ($, millions)	0–27	0–29	0–56

This finding leads to the following policy options:

Policy Option 3-1: Invest in economic incentives for CDR activities such as reforestation, improved forest management, forest products, bioenergy, direct air capture, and CO_2 storage in southern West Virginia and other disadvantaged communities in the state.

Policy Option 3-2: Increase resources for the West Virginia Department of Commerce's Division of Natural Resources (WVDNR) and Division of Forestry (WVDOF) as well as the West Virginia Department of Agriculture (WVDA) to provide technical assistance and advise small forest, farmland, rangeland, and wetland owners on the economic potential participation details of carbon credit or offset programs and markets.

Policy Option 3-3: Increase resources for West Virginia University (WVU) Extension and West Virginia State University (WVSU) Extension and outreach representatives from colleges and universities throughout the state to advise small forest, farmland, and wetland owners on the economic potential of carbon credit and details of participation. In addition, the WVDEP should prioritize and accelerate its Wetland Rapid Assessment to identify wetlands to preserve and restore.

Policy Option 3-4: Develop a federal and state tax credit for nature-based CDR investments (including forest products) similar to the existing federal carbon oxide sequestration tax credit (Internal Revenue Code Section 45Q) that focuses on technological options (e.g., direct air capture (DAC)).

Policy Option 2-3: Include carbon sequestration technologies in West Virginia's agricultural equipment credit (Code 11-13K-1), and increase the credit so it is more in line with neighboring states.

Open CDR Opportunities While Protecting West Virginia's Ecology, Conservation, and the Environment

Finding 4: Some CDR methods may have side effects that impact the state's ecology (living organisms), conservation (natural resources), and environment (air, water, soil). Taking into account both the opportunities and challenges of each CDR option, the West Virginia University team believes that the potential societal benefits outweigh the societal costs based on what we know today. This assessment is based on a presumption that care is taken to protect local communities.

The team looked at the potential opportunities and challenges of each CDR method and judged that the societal benefits outweighed the societal costs if properly managed, as illustrated in tables throughout this guide.

This finding leads to the following policy option:

Policy Option 4-3: Take steps to protect the economic health, human health, and ecology of local communities near CDR facilities and related CO_2 storage operations by

- **monitoring potential concerns;**
- **improving the communities' environmental and ecological quality (e.g., drinking water, reforestation, and wildlife habitats);**
- **maximizing economic co-benefits; and**
- **responding to unanticipated issues that arise including, but not limited to, economic harm and environmental degradation.**

Nurture West Virginia's Disadvantaged Communities

Finding 5: Socio-economically disadvantaged communities in West Virginia can benefit from CDR activities. However, care must be taken to ensure that past mistakes are not repeated by ensuring that local communities are involved in decision-making from the earliest stages and that they economically benefit from CDR investments.

In the past, West Virginians have not always received the economic benefit of their natural resources. Often, these benefits went only to the more economically-advantaged—those who owned land—or those who lived entirely out of the state.

The shortfalls of the past need to be avoided in future investments to ensure that communities are involved at the beginning of the process and that they benefit from the job creation that will result from CDR investments. Not all members of a community are appropriate for the jobs that will be available, however, so actions need to be taken to ensure that everyone can benefit from their local natural resources.

Therefore, each community will need to make its own decisions, with technical and financial assistance (including proper compensation for participating attendees) to ensure that they are comfortable with the CDR activities in their community. This is particularly the case for DAC and carbon storage. That being said, as noted earlier, CDR can potentially bring jobs and economic prosperity to the poorest regions of West Virginia.

This finding leads to the following policy options:

Policy Option 5-1: Facilitate access to federal, state, and non-profit CDR-related assistance programs for historically underserved communities to create economic opportunities and provide environmental, health, and safety protection.

Policy Option 5-2: Require that CDR companies negotiate a community benefit agreement that includes the design and use of a community fund and addresses community concerns and recommendations from stakeholders (i.e., both landowners and non-landowners).

Policy Option 5-3: Require companies to build safe carbon capture facilities that provide economic benefits to local communities, including but not limited to local job creation and development projects, and prioritize use of environmentally degraded sites (e.g., brownfields, abandoned mine lands).

Policy Option 5-4: Establish a state fund developed from fees on carbon capture activities, and redistribute it to benefit local communities throughout West Virginia and to address unforeseen circumstances.

Recommendations

Today, some CDR activities, like the natural methods, have been long studied and are ready to go. Others, like DAC and CO_2 storage, are still in the demonstration stages. Yet others, like the carbon credit markets, are still experimenting to find the right economic model.

To take advantage of being "first to market," West Virginia should proactively enact policies to enable its participation in CDR activities. Decisions to undertake these activities, however, will require community involvement and access to assistance programs so these investments are made appropriately and wisely, avoiding the adverse consequences that occurred in West Virginia's past.

During August and September 2022, the team developing this policy guide held three stakeholder roundtables to gather feedback on the guide, with a focus on the policy options provided in this chapter. Roundtable participants were also asked, following the event, to prioritize the policy options relevant to their topic based on the "4 Es" of policy analysis (effectiveness, efficiency, equitability, ease of political acceptability). More details of this process are provided in Appendix C.

Based on that input, the stakeholders identified the "top 10" policy options which we offer here as recommendations. The team developing the policymaker agreed with the stakeholder "top 10" policy options. **These recommendations are listed below in order of their presentation in the guide, not in priority order**.

Table 6.6. West Virginia University Bridge Initiative Carbon Dioxide Removal (CDR) and West Virginia Findings and Top Ten Recommendations (West Virginia University, 2022)

	Findings	Top Ten Recommendations (not in priority order)
C A	**Create Carbon Reduction Opportunities in West Virginia** **Finding 1:** West Virginia has the most scientific and technological carbon reduction potential for CDR options using natural methods (such as forests, agriculture, wetlands, and forest products, which can be implemented immediately) as well as bioenergy with carbon capture and sequestration (BECCS) (which can take varying amounts of time depending on the technology chosen) and direct air capture (DAC) (which requires additional time for the development of appropriate carbon sequestration pathways). Carbon mineralization is not an option due to the state's geology. Whatever CDR options are chosen, care should be taken to establish appropriate standards and verification processes.	**Recommendation 1**: Work with Federal agencies (U.S. Department of Energy (DOE) and U.S. Department of Agriculture (USDA)) and leading nongovernmental organizations to develop appropriate standards for net carbon accounting of stored and sequestered carbon. **Recommendation 2:** The USDA, working with the DOE, should request to fund a study by the National Academies of Science, Engineering, and Medicine (NASEM) to determine the optimal harvest cycle for maximizing the carbon removal potential by forests and forest products. The study should also consider the ecological factors (e.g., the role trees play in mitigating flooding), social factors (e.g., landowner goals), and economic factors (e.g., life cycle analysis of wood products and impact on the forest products industry).
R	**Restore Carbon Into West Virginia's Natural Resources** **Finding 2**:The chief challenge for the implementation of BECCS and DAC options is developing a better understanding of the ability to store CO_2 in West Virginia. There are many possible locations, but site-specific analysis and demonstration projects are needed to assess the technical viability of carbon storage options for BECCS and DAC.	**Recommendation 3:** Incorporate BECCS into the existing U.S. Renewable Fuel Standard. **Recommendation 4:** Fund a study that examines both community and technical opportunities and challenges to identify suitable locations for DAC demonstration projects in West Virginia. This study, perhaps funded by the new DOE Office of Clean Energy Demonstrations, should include financial support for creation and maintenance of community infrastructure (e.g., roadways, water, noise prevention) that might be impacted by DAC development and operations.
B	**Benefit West Virginia's Economic Prosperity and Create Jobs for West Virginians** **Finding 3:** CDR has the potential to generate economic prosperity and job creation, particularly in West Virginia's coal communities and other rural communities. The natural options are in rural areas and abandoned mine lands,	**Recommendation 5:** Invest in economic incentives for CDR activities such as reforestation, improved forest management, forest products, bioenergy, DAC, and CO_2 storage in southern West Virginia and other disadvantaged communities in the state. **Recommendation 6:** Increase resources for the West Virginia Department of Commerce's Division of Natural Resources (WVDNR) and Division of Forestry (WVDOF) as well as the West Virginia Department of Agriculture (WVDA)

	while potential carbon storage sites for DAC are near the hardest-hit coal communities in southern West Virginia as well as oil and gas reservoirs throughout the state.	to provide technical assistance and advise small forest, farmland, rangeland, and wetland owners on the economic potential and participation details of carbon credit or offset programs and markets. **Recommendation 7:** Increase resources for West Virginia University (WVU) Extension and West Virginia State University (WVSU) Extension and outreach representatives from colleges and universities throughout the state to engage small forest, farmland, and wetland owners on the economic potential of carbon credit and details of participation. In addition, West Virginia Department of Environmental Protection (WVDEP) should prioritize and accelerate its Wetland Rapid Assessment to identify wetlands to preserve and restore.
O	**Open CDR Opportunities While Protecting West Virginia's Ecology, Conservation, Economy, and the Environment** **Finding 4:** Some CDR methods may have side effects that impact the state's ecology (living organisms), conservation (natural resources), economy (jobs), and environment (air, water, soil). Taking into account both the opportunities and challenges of each CDR option, the West Virginia University team believes that the potential societal benefits outweigh the societal costs based on what we know today. This assessment is based on a presumption that care is taken to protect local communities.	**Recommendation 8:** Take steps to protect the economic health, human health, and ecology of local communities near CDR facilities and related CO_2 storage operations by ● monitoring potential concerns; ● improving the communities' environmental and ecological quality (e.g., drinking water, reforestation, and wildlife habitats); ● maximizing economic co-benefits; and ● responding to unanticipated issues that arise including, but not limited to, economic harm and environmental degradation.
N	**Nurture West Virginia's Disadvantaged Communities** **Finding 5:** Socio-economically disadvantaged communities in West Virginia can benefit from CDR activities. However, care must be taken to ensure that past mistakes are not repeated by ensuring that local communities are involved in decision-making from the earliest stages and that they economically benefit from CDR investments.	**Recommendation 9:** Facilitate access to federal, state, and non-profit CDR-related assistance programs for historically underserved communities to create economic opportunities and provide environmental, health, and safety protection. **Recommendation 10:** Require that CDR companies negotiate a community benefit agreement that includes the design and use of a community fund and addresses community concerns and recommendations from stakeholders (i.e., both landowners and non-landowners).

Appendices

Appendix A: Participating West Virginia University Faculty, Staff, And Students

This policymaker guide was developed by the WVU faculty, staff, and students listed below under the Bridge Initiative for Science and Technology Policy, Leadership, and Communications, directed by Joan Centrella. Eddie Brzostek, Shikha Sharma, John Deskins, Dave McGill, and Jamie Shinn led the working groups that developed the content for this guide. Deborah Stine was the study director as a consultant to WVU, and Brooke Eastman was the Bridge Postdoctoral Science Policy Fellow, who was a major contributor to the policymaker guide.

CARBON DIOXIDE REMOVAL AND WEST VIRGINIA COMMITTEE MEMBERS

Graham Andrews - Research Associate Professor, Geology

Jorge Atiles - Dean, Extension and Engagement; Director, WVU Extension Service

Brandy Brabham - Extension Agent, Agriculture and Natural Resources

Eddie Brzostek - Associate Professor, Biology

Steve Chhin - Associate Professor, Quantitative Forest Management

John Deskins - Director, Bureau of Business and Economic Research (BBER); Assistant Dean for Outreach and Engagement, John Chambers College of Business and Economics; Associate Professor, Economics

Michael Dougherty - Professor and Extension Specialist, WVU Extension and Davis College

Kathryn Gazal - Associate Professor, Forest Resources Management

Stefanie P Hines - Teaching Assistant Professor, Forestry and Natural Resources

John Hu - - Statler Chair Professor, Department of Chemical & Biomedical Engineering; Director, Center for Innovation in Gas Utilization & Research (CIGRU)

Charlene Kelly - Teaching Associate Professor, Forest Resources Management

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Xingbo Liu - Associate Dean for Research; Statler Chair of Engineering, Statler College; Professor, Department of Mechanical & Aerospace Engineering

Dave McGill - Professor & Extension Specialist, Forest Resources Management

Brenden McNeil - Professor, Geography

Ember Morrissey - Assistant Professor, Environmental Microbiolog

Kevin Orner - Assistant Professor, Department of Civil & Environmental Engineering

William Peterjohn - Professor, Biology

Jamie Schuler - Associate Professor, Silviculture; Program Coordinator, WVU Forests

Shikha Sharma - Professor, Geology; Director, IsoBioGeM Laboratory

Jamie Shinn - Assistant Professor, Geography

Jeff Skousen - Professor, Soil Science; Extension Specialist, Land Reclamation

Mark Sperow - Associate Professor, Resource Economics & Management

Samuel Taylor - Assistant Director, Strategic Partnerships & Technologies, WVU Energy Institute

Jingxin Wang - Director, Center for Sustainable Biomaterials & Bioenergy Center; Associate Director for Research; Davis Michael Professor of Forestry and Natural Resources

Amy Welsh - Associate Professor, Wildlife & Fisheries Resources

STUDY STAFF

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Deborah Stine - Study Director, Consultant to WVU, Science & Technology Policy Academy

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Timothy Hoheneder

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Payton Seats

Rachel Yesenchak

Master's Students:

Scott Lopez

Eric Sjöstedt

Appendix B: Study Process

The purpose of this appendix is to provide an overview of the process we used to produce this policy guide at WVU's Bridge Initiative for Science and Technology Policy, Leadership, and Communications.

This policymaker guide provides the views of WVU faculty and staff who are experts in the topics discussed in the guide. The Bridge staff support the effort by writing the policymaker guide based on the faculty's and research staff's views, providing research support, managing the logistics of bringing the faculty and stakeholders together, moderating the peer review process, summarizing meetings, and developing consensus on the policy options and recommendations.

The timeline of activities is provided below.

Step	Timeframe
1. Concept Development a. Identify a science and technology (S&T) policy area of interest to West Virginians based on discussion with WVU leadership and faculty/staff, stakeholders, and other experts b. Gather information and data on current policy and science and engineering research in this area (the "status quo") c. Identify relevant WVU faculty/staff and stakeholders d. Develop draft statement of work (SOW) e. Consult with WVU faculty/staff, West Virginia state agency staff, and non-governmental organizations on SOW f. Revise SOW based on feedback g. Recruit working group chairs	Spring-Summer 2021
2. Kick-off Meeting a. President and Vice President of Research explain importance of initiative b. Attendees engage in breakout sessions to develop working groups and discuss draft SOW c. Finalize SOW (see details below)	September 2021
3. Working Groups a. Working groups meet to develop findings and policy options to respond to those findings b. Outline policymaker guide by working group c. Develop draft policymaker guide text, by working group; this is achieved through an iterative process on a roughly weekly basis where Bridge staff develop text based on faculty/staff discussions, which are then reviewed by the faculty/staff	September 2021 - March 2022

4. Full Policymaker Guide Text a. Synthesize sections based on individual working groups to develop full draft of policymaker guide b. All working groups meet to review and finalize full policymaker guide draft (version 1)	March-April 2022
5. External Review a. Send policymaker guide (version 1) to non-WVU experts for peer review and to the staff of several West Virginia agencies to gather their thoughts and questions b. Incorporate review comments into text (version 2)	May-July 2022
6. Stakeholder Roundtables a. Expand stakeholder identification based on draft policymaker guide contents b. Send policymaker guide (version 2) to stakeholders for comment and post to website for public comment c. Three stakeholder "listening" roundtables review policy options and develop and prioritize recommendations to policymakers (see details below)	August 2022
7. Policymaker Guide Text Finalized a. Working groups meet individually and then in a plenary session to discuss stakeholder input b. Working groups meet in plenary session to finalize and prioritize policymaker guide recommendations	September 2022
8. Policymaker Guide Formalized and Released a. Edit, format, and prepare policymaker guide for dissemination b. Release policymaker guide and disseminate it to policymakers, stakeholders, and the public	Fall 2022 – Winter 2023

STATEMENT OF WORK (SOW)

The study began with the following statement of work:

- What actions, if any, should national, state, and local West Virginia policymakers take to enhance the removal and storage of CO_2 from the atmosphere to reduce climate variation, increase economic opportunities, and create jobs for West Virginians?

Four working groups were asked to focus on the following questions:

- Working Group 1 (Sci/Tech): What are potential scientific and technological opportunities and challenges to the removal and storage of CO_2 from the atmosphere in West Virginia?

- Working Group 2 (Economic): How could the effective and efficient removal and storage of CO_2 from the atmosphere enhance economic prosperity and job creation in West Virginia?
- Working Group 3 (Eco/Enviro/Conservation): What are potential new ecological, conservation, and environmental opportunities and challenges to the removal and storage of CO_2 from the atmosphere in West Virginia?
- Working Group 4 (Disadvantaged Communities): What are the associated opportunities, challenges, risks, and empowerment potential for traditionally socio-economically disadvantaged communities, including those located in former coalfields and communities of color?

All meetings were held via Zoom. The assessment and prioritization of these policies was initially done according to their effectiveness, economic efficiency, equity, and ease of political acceptability. Additionally, stakeholder input was incorporated to finalize policy recommendations.

KICK-OFF MEETING

The agenda for the kick-off meeting, held via Zoom, is provided below:

Opportunities for Carbon Removal and Storage in WV to Reduce Climate Variation, Increase Economic Opportunities, and Create New Jobs for West Virginians

September 24, 2021

Meeting Agenda

11:30 am – Introductory Remarks

- Dr. Joan Centrella, Director, Bridge Initiative in Science and Technology Policy, Leadership, and Communications, WVU

11:35 am – Welcome

- E. Gordon Gee, President, West Virginia University

11:40 am – Keynote: Overview of Carbon Dioxide Removal (CDR) Opportunities and Challenges

- Joseph Hezir, Principal, Energy Futures Initiative

12:10 pm – Research Office Perspective

- Dr. Fred King, Vice President for Research and Professor, WVU

12:15 pm – Kickoff Meeting Goals

- Dr. Deborah Stine, Study Director, Consultant to WVU

12:25 pm – Breakout sessions for Working Groups

- Working Group 1 (Sci/Tech): What are potential new scientific and technological opportunities and challenges to the removal and storage of carbon dioxide from the atmosphere in West Virginia?
- Working Group 2 (Economic): What are potential new economic opportunities and challenges to the removal and storage of carbon dioxide from the atmosphere in West Virginia?
- Working Group 3 (Eco/Enviro/Conservation): What are potential new ecological, conservation, and environmental opportunities and challenges to the removal and storage of carbon dioxide from the atmosphere in West Virginia?
- Working Group 4 (Disadvantaged Communities): What are the potential opportunities that could be particularly relevant for former coal-field, economically-disadvantaged communities and for West Virginians of color—particularly those that might take advantage of former coal mines and reclamation projects where West Virginia's geology might provide unique opportunities for natural removal and storage of carbon dioxide?

12:55 pm – Final thoughts

1:00 pm – Adjourn

ROUNDTABLES

The Bridge Initiative hosted three topical roundtables, held via Zoom, to gather feedback on the policy options developed by the working groups. Roundtable participants included key stakeholders interested in CO_2 removal in West Virginia from business and industry, government, non-governmental organizations, faith-based community leaders, and private landowners. Appendix C provides a list of those who participated. The roundtables were broken down into the following topics based on the content of the policymaker guide:

- Roundtable 1: Agriculture, Forest Products, and Bioenergy

  (Tuesday, August 16, 2022, 12:00pm-1:30pm)

- Roundtable 2: Family Forests, Wetlands

  (Friday, August 19, 2022, 9:00am-10:30am)

- Roundtable 3: Direct Air Capture and Carbon Capture; Community Benefit

  (Monday, August 22, 2022, 12:30pm-2pm)

During each roundtable, stakeholders were asked to review the policy options then prioritize them based on the criteria of effectiveness (likelihood of meeting the societal goal), efficiency ("best bang for the buck"), equity (winners and losers), and ease of political acceptability (the degree to which key policymakers and stakeholders would oppose or support the policy). WVU faculty/staff and the Bridge team were in "listening mode," intentionally focused on hearing the views of the stakeholders, as well as asking clarifying questions, rather than presenting their own views during the conversation.

The roundtables, each held over 2 hours, had the following overall agenda:

Welcome

Dr. Joan Centrella, Director, Bridge Initiative in Science and Technology Policy, Leadership, and Communications

Roundtable Goals

Dr. Deborah Stine, Study Director, Consultant to WVU

WVU Faculty and Staff Introductions

Roundtable Participant Introductions, with Overview Thoughts on the Policymaker Guide

Discussion and Prioritization of Policy Options

- How would you rank the options in terms of effectiveness (most likely to reach a societal goal)?
- How would you rank the options in terms of efficiency (biggest bang for the buck)?
- How would you rank the options in terms of equity (fairness)?
- How would you rank the options in terms of ease of political acceptability (support/opposition of policymakers and key stakeholders based on their priorities)?

What is your overall assessment in terms of ranking the options?

Final thoughts

Conclusion

Appendix C: Roundtable Participants

West Virginia University's Bridge Initiative for Science and Technology Policy, Leadership, and Communications acknowledges the helpful comments from the following roundtable participants who attended one or more of the Roundtable Discussions, held in August 2022:

Kyle Aldinger
Resource Conservationist, USDA NRCS

Chelsea Barnes
Legislative Director, Appalachian Voices

Jeffrey Barr
State Resource Conservationist, USDA-NRCS

Shelley Birdsong-Maddex
Sr. Director CFR, West Virginia University Foundation

Kelly Bragg
Energy Development Specialist/Coordinator, WV Office of Energy/ WV Clean Cities

Eriks Brolis
Director, Nature & Economy, The Nature Conservancy

Eric Carlson
Executive Director, WV Forestry Association

Cory Chase
Program Director, WV Highlands Conservancy

Sarah Conley-Ballew
Director, Sustainable Energy Solutions Program, Rural Action, Inc.

Jenna Dodson
Staff Scientist, WV Rivers Coalition

Diana Dombrowski
Economic Diversification Assistant, Appalachian Voices

Robert Eckenrode
Lead Forest Carbon Analyst, Green Assets

Jessica Ferson
Program Coordinator, American Forest Foundation

Crystal Good
Publisher at BlackbyGod

Sarah Hall-Bagdonas
Senior Forestry Manager, American Forest Foundation

Jacob Hannah
Director of Conservation, Coalfield Development Corporation

Mitchell Hescox
President, The Evangelical Environmental Network

Jeremy Jeffers
Council Representative, Carpenters Local 439/Eastern Atlantic States Carpenters

Allen Johnson
Coordinator, Christians for the Mountains

Andrew Jones
Carbon Dioxide Removal Technology Manager, DOE/NETL

Michael Jones
Public Lands Campaign Coordinator, WV Rivers Coalition

Morgan King
Climate Campaign Coordinator, WV Rivers Coalition

Ryan Kirkpatrick
Intern, Our Future West Virginia

James Kotcon
Associate Professor, West Virginia University

Rick Landenberger
Service Associate Professor, West Virginia University

James McKitrick
Senior Policy Manager, American Forest Foundation

Joe McNeel
Director, Appalachian Hardware Center West Virginia University

Andrea Miller
Sustainable Forestry Program Manager, Rural Action

Todd Miller
Director of Conservation Programs, Nature Conservancy

Anthony Pappas
Owner/Lead Consultant, Heritage Habitat and Forestry

Oishi Sanyal
Assistant Professor, West Virginia University

Julia Sullivan
Watershed Restoration Project Manager, Rural Action

Trina Wafle
Assistant Director, West Virginia University Energy Institute

Adam Wells
Regional Director, Appalachian Voices

Bill Woodrum
Senior Program Officer, Claude Worthington Benedum Foundation

Appendix D: West Virginia's Natural Carbon Sequestration Potential

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Summary

- West Virginia can increase its natural carbon sequestration capacity through the adoption of management and restoration practices.
- We estimated the sequestration potential of West Virginia's lands by selecting land-use[1] categories and applying management practices to them in a simulation that spanned from 2022 to 2050. The land-use categories used were forest, agriculture, abandoned mine lands, and wetlands. Estimates of the land area for each land-use category and carbon sequestration values of management practices were obtained from previously published surveys and studies.
- We simulated the adoption rate of management practices as a three-percent annual increase in management for each land-use category–i.e., an additional three percent of the total land area in each category became managed each year.
- The results of the simulation showed that forested land has the greatest potential for carbon sequestration, with an additional average of 3.5 $MMTCO_2e$[2] sequestered annually by 2050. Agricultural land management had the second greatest sequestration potential, removing an additional average of 0.76 $MMTCO_2e$ annually from the atmosphere by 2050. Restoration of abandoned mine land to forests led to an average 0.16 $MMTCO_2e$ annual increase in sequestration by 2050, and wetland restoration had the potential to additionally sequester an average of 0.048 $MMTCO_2e$ per year.

Land-use Classification and Area Estimation

To simulate management practices and their outcome on carbon sequestration, we began by categorizing West Virginia into five land-use categories:

- Agricultural – cropland

[1] We have named the land categories "land use", however in many cases they may represent land cover. The distinction between the two can be muddled, particularly when spanning multiple categories. For example, agriculture can be both an overarching land use and land cover category, but forest land cover can include multiple land uses. For the ease of reading, we use the term "land use" throughout this description.

[2] One $MMTCO_2e$ is one million metric tons of CO_2 equivalent. CO_2 equivalent is a measure used to compare the warming potential of various greenhouse gasses (e.g., methane, nitrous oxide) on a common scale by converting their climate warming potential to equivalent units of CO_2. One metric ton is equal to 1.102 U.S. tons.

- Agricultural – pasture
- Forest
- Wetlands
- Abandoned Mine Lands

These designations and their land area estimates were gathered from five sources between federal, state, and non-profit groups (Table D.1). Each group has their own estimation protocol, with some overlap occurring between land-use designations. The sum of all land area, minus abandoned mine land, and including estimates of both developed land area and the area of water (U.S. Department of Agriculture, 2017) total 15,454,567 acres. This estimate is 0.46% larger than the actual total area of the state–15,384,320 acres. This error represents the disparate methods of land-use area estimation and classification among the information sources. Abandoned mine land has been left out of the total acreage calculation to estimate error because it overlaps with agricultural, forest, wetland, water, and developed land-use area estimates.

Table D.1. Total Acreage of Five Land-Use Categories in West Virginia

Land-Use Category	Area (acres)	Source
Agricultural - cropland	947,710	USDA National Agricultural Statistics Survey 2017 Table 8 0 "Total cropland" (USDA National Agricultural Statistics Service 2017)
Agricultural - pasture	1,016,457	USDA National Agricultural Statistics Survey 2017 Table 8 - "Permanent pasture and rangeland, other than cropland and woodland pastured" (USDA National Agricultural Statistics Service, 2017)
Forest	12,046,000	USDA Forest Service Forests of West Virginia 2016 Report (Morin et al. 2016)
Wetlands	100,000	West Virginia Department of Environmental Protection Wetland Program Plan 2016-2020 (WVDEP, 2015)
Abandoned mine lands	200,000	Appalachian Voices Repairing the Damage 2021 Report (Savage, 2021)

General Simulation Approach

We simulated the natural carbon sequestration potential from 2022 to 2050 by converting a percentage of total land to managed land in each land-use category each year, following the approach from Cameron et al. (2017). We simulated a scenario in which an additional three percent of the total land in each land-use category was converted to management each year. In each year, the estimated fractional increase in carbon sequestration for each management practice was applied to the managed land. Fractional increases for management practices were obtained from models, surveys, and research studies (Table D.2). The mean and standard deviations of all fractional increases taken from the models, surveys, and studies were used to create a normal distribution—except in the case of agricultural land use, where fractional increases were implemented in a triangular distribution (see *Agricultural carbon sequestration potential estimation* for details). In each year, each land-use specific distribution was sampled 50,000 times and multiplied by the managed area of its corresponding land-use. The resulting product was a distribution of the estimated sequestration potential of each land-use category. Annual sequestration potential for each land-use category in 2050 was estimated as the mean of the distribution product in 2050. And cumulative sequestration potential was the sum of the mean distribution product for each land-use category for the years 2022-2050. Ninety percent confidence intervals were calculated for both annual and cumulative sequestration increase in 2050 for each land-use category.

Table D.2. Management Parameters Used in the Simulation

Land-use category	Mode mgmt increase (MTCO2 per acre)	Minimum mgmt increase (MTCO2 per acre)	Maximum mgmt increase (MTCO2 per acre)	Baseline carbon sequestration (MTCO2 per acre)	Mean mgmt increase (fraction)	Standard deviation mgmt increase (fraction)	Sources
Agricultural - cropland	0.718	0.000	1.791				Swan et al. (2020)
Agricultural - pasture	0.055	0.000	0.244				Swan et al. (2020)
Forest				0.689	1.313	0.205	Schuler (2004); Schuler et al. (2017)
Wetlands				0.212	1.783	0.205	Yavitt (1994); Bernal & Mitsch (2011); Nahlik & Fennesy (2016)
Abandoned mine lands				0.096	10.358	7.406	Parton et al. (1987); Sperow (2006); Bouquot &

							Sperow (2006); Sharma and Wang (2011); Fox et al. (2020).

Agricultural Carbon Sequestration Potential Estimation

In each of the 55 counties in West Virginia, estimates of the sequestration potential for agricultural management were obtained from USDA COMET-Planner (Swan et al. 2020). Specifically, we estimated the carbon dioxide equivalent sequestration value for four cropland practices[3]:

- Conservation Crop Rotation (CPS 328) - Decrease Fallow Frequency or Add Perennial Crops to Rotations
- Cover Crop (CPS 340) - Add Non-Legume Seasonal Cover Crop (with 25% Nitrogen Fertilizer Reduction) to Non-Irrigated Cropland
- Residue and Tillage Management - Reduced Till (CPS 345) - Intensive Till to Reduced Till on Non-Irrigated Cropland
- Nutrient Management (CPS 590) - Replace Synthetic Nitrogen Fertilizer with Compost (Carbon:Nitrogen Ratio of 20) on Non-Irrigated Croplands

All practices can be applied simultaneously and represent management steps that allow for continued cropping. These practices were similar to those applied to estimate the cropland carbon sequestration potential in California (Baker et al. 2020). The one major difference in the practices selected for West Virginia was they were specific for non-irrigated cropland, as less than 0.5% of cropland in West Virginia is irrigated (USDA National Agricultural Statistics Service 2017).

For pastureland, a conservative grazing management practice was applied to the pasture acreage in each county to estimate the potential carbon sequestration potential:

- Prescribed Grazing (CPS 528) - Grazing Management to Improve Rangeland or Non-irrigated Pasture Condition

COMET-Planner estimates the potential carbon sequestration for each of these agricultural management practices at the county level and reports the result in carbon dioxide equivalent units. These units represent the net change of greenhouse gasses (including methane and nitrous oxide) in equivalent units of carbon dioxide. COMET-Planner reports a middle, minimum, and maximum value of carbon dioxide equivalent emission reductions per acre.

[3] Detailed descriptions of the cropland and grazing practices used in COMET-Planner are available in Swan et al. (2020).

To estimate the state-level greenhouse gas emission reduction from agricultural management practices, we averaged the county-level reduction estimates to create a statewide per-acre rate of carbon dioxide equivalent reduction. The average was used as the mode in a triangular distribution (because the mean and standard deviation were unknown), with the minimum and maximum values representing the ends of the triangle. Negative minimum values were truncated to zero, which assumed that management practices that led to negative sequestration would not be applied. The triangular distribution was sampled 50,000 times annually and multiplied by the annual acreage in management. The median and standard deviations of the product distribution were estimated to determine the annual values of carbon dioxide equivalent offset due to management. The simulation was run from 2022 to 2050 to estimate the total carbon sequestration potential through time of conservation agricultural practices[4].

The agricultural land use simulation is distinct from that of the other land uses because it does not include a baseline sequestration rate. In all other land-use categories, a management fractional increase value is multiplied by a baseline sequestration rate to calculate the annual increase in sequestration due to management. Instead, the COMET-Planner model estimates the increase in sequestration due to management, irrespective of a baseline value.

Forest Carbon Sequestration Potential Estimation

To estimate the carbon sequestration potential of forestry management practices, we used estimates of forest management practices from long-term studies at the Fernow Experimental Forest in Parsons, WV (Table D.2). The total forest acreage under management in the simulation was increased by three percent each year. Forests not under management practices stayed at a constant sequestration rate. The mean and standard deviations of the increased sequestration fraction from the management practices were used to create a normal distribution. In each year, the distribution was sampled 50,000 times and each time multiplied by the managed area of forests. We simulated from 2022 to 2050. The annual sequestration increase in 2050 of managed land was the average annual sequestration rate enhancement for 2050.

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[4] COMET-Planner truncates the per-acre estimate of carbon dioxide reduction to two decimal places. This creates a 1% error interval for each estimate, for each practice, in each county. Across 55 counties with 5 practices each, the error created by this truncation is noteworthy. Additionally, the conservative pasture practice selected for this analysis was quite conservative compared to the other available approaches–e.g., adding shrub and woody vegetation to pastures. All the cropland practices chosen in the *Getting to Neutral* report seemed to represent the most conservative approach, as they would continue to allow landowners to have working and productive lands. In that spirit, both conservative pastureland and cropland practices were chosen in this analysis. Finally, the minimum error was truncated in the triangle distribution, and the resulting minimum confidence level of the 90% confidence interval was also truncated to zero. The use of a triangle distribution represents a “best guess” for the true distribution of the management effects from COMET-Planner.

And the cumulative increase in sequestration from 2022 to 2050 was calculated as the sum of annual values[5].

Wetland Carbon Sequestration Potential Estimation

Wetlands currently store large amounts of carbon, but if those wetlands are flooded, drained, disturbed or warmed, this storehouse of carbon (which began 10,000 years ago in West Virginia) along with other greenhouse gases will be released into the atmosphere. Thus, it is important to avoid disturbing or developing wetland areas. Restoring forested wetlands and providing shade around their margins (forested buffers) can make a significant contribution toward reducing climate change and subsequent carbon release.

The total acreage of wetlands in West Virginia is not known. Approximately 66,400 acres of wetlands have been mapped, but the Department of Environmental Protection estimates that there are likely 100,000 acres of wetlands in the state (WVDEP, 2015), and potentially as many as 200,000 acres. Additionally, the land-area accounting of wetlands likely overlaps the estimates of agricultural land, forests, developed land, and abandoned mine lands. To estimate the carbon sequestration potential of wetland management and restoration, we estimated that 400,000 additional acres of wetlands could be restored (Watershed Resources Registry, 2021). Using estimates from Nahlik & Fennessy (2016), we projected restoring degraded wetlands would increase carbon storage capacity by 178.3% (Table D.2). We used an implementation scenario of adding 10,000 acres of restored wetlands annually[6], recognizing that this goal will require a substantial financial investment.

There is a high degree of uncertainty in estimating the baseline carbon sequestration rate of wetlands. Yavitt (1994) estimates that West Virginia's wetlands are net carbon sources. However, Yavitt (1994) argued that more rigorous study of wetlands was required to have confidence in that conclusion. A more recent study of wetlands in Ohio argues that wetland sequestration rates are often underestimated by non-rigorous methods (Bernal & Mitsch 2011). Bernal and Mitsch (2011) are critical of previous estimation approaches, arguing that carbon budgets made using modern techniques are more accurate. Finally, Weider et al. (1990) hypothesized that decomposition in West Virginia wetlands was driven strongly by sulfate deposition. In 1990, the sulfate deposition rate was 39 kg per ha, and in 2020, the deposition rate was 4 kg per ha (National Atmospheric Deposition Program 2020). Sulfate deposition has decreased by 90% since the work claiming West Virginia's wetlands as net carbon sources was

[5] The forest simulation relies on estimates from four long-term studies at Fernow Experimental Forest in West Virginia. They are among the longest-running timber management studies in the world, and they are located in central Appalachia. However, as with many timber management studies, the results of the productivity increase from management are reported for merchantable timber only. In stands managed for timber, this value likely represents the total amount of wood biomass in a stand. However, in the control stands, there may be snags, damaged trees, or undesirable species that were unaccounted for in estimating biomass.

[6] This method assumes that the increased carbon sequestration of wetland management practices will persist through 2050. As with the forest analysis, there are few studies that have tracked management and restoration effects for this long. Finally, the estimate of carbon storage increase from restoration is aggregated at the national level.

done. For all these reasons, we were skeptical of an overarching claim that West Virginia's wetlands are net carbon sources.

Without the capacity to conduct modern estimates of West Virginia wetland carbon sequestration, we used a baseline sequestration rate of 0.212 metric tons CO_2 (0.233 tons) annually per acre. This value represents half of the estimated sequestration rate using modern techniques in a reed-bulrush marsh in Ohio (Bernal & Mitsch 2011); it splits the difference between a mid-productivity Ohio wetland estimated with modern techniques and the average estimated sequestration of a West Virginia marsh estimated with low-technology peatland carbon pool techniques[7].

Abandoned Mine Land Carbon Sequestration Potential Estimation

There are 200,000 acres of abandoned mine lands in West Virginia (Savage, 2021). Their reclamation status and quality are difficult to map and track because of the loopholes in both state and federal regulation. However, the vast majority of "restored" abandoned mine lands were graded and seeded with grass.

The greatest potential for these lands to store carbon naturally is by conversion to forest. Reforestation may be challenging, however, due to soil compaction and soil conditions. In addition, disturbance of this surface can release acid that has been "capped."

To estimate the sequestration potential of forest conversion of abandoned mine lands we relied on values from research projects that converted abandoned mine lands to forest (Table D.2). These estimates were applied to abandoned mine lands in the same adoption scenario as other land uses: three percent of abandoned mine lands (6,000 acres) would be reforested each year from 2022-2050. This rate of reforestation may be an optimistic goal; however, we lack information to do a more specific analysis.

The mean and standard errors of the sequestration increase estimates from previous research were used to create a normal distribution. That distribution was sampled 50,000 times annually, each time multiplying the sampled value by the number of acres managed. The mean of the distribution product in 2050 was the annual increase in carbon sequestration, and the sum of the annual means was the cumulative increase in by 2050[8].

Comparison to Previous Research

Sharma and Wang (2011) estimate that the natural sequestration potential of West Virginia could be increased by 52.7%. Their approach differs from this one in multiple ways. They assume immediate 100% adoption of management practices in each land-use category. Additionally, their calculation includes the conversion of 40% of agricultural land to forest.

[7] The estimation of carbon sequestration rates and potential ignores the flux of other greenhouse gasses, especially methane, which has 28 times the greenhouse warming potential of CO_2 over 100 years.

[8] The estimates of carbon sequestration from reforestation of abandoned mine lands vary widely. All the variation is considered in this process, which explains the large level of uncertainty around this practice. Additionally, the amount of carbon a new forest sequesters as it matures certainly decreases, although this information is rarely included in abandoned mine land reforestation research. Since our simulation spans 29 years, the decline in new forest productivity with age may not have a large effect.

Finally, in contrast to our approach, Sharma and Wang (2011) include an increase in sequestration due to increased lifetime of carbon in wood products. Overall, our modeling scheme, including the parameter selection and the exclusion of wood product fate, as well as the three-percent annual management adoption rate, represents a more conservative estimate of the carbon sequestration potential of West Virginia. Particularly, the agricultural management practices allow farmers to keep land as cropland and pasture, and the forest management practices are all based on various timber harvest treatments. These approaches offer a realistic estimate by keeping working landscapes for the landowners of West Virginia.

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Appendix E: CO_2 Mineralization Potential in West Virginia

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Some geological options for offsetting West Virginia's carbon emissions focus on mineralizing CO_2 as carbonate through combination with rocks or industrial wastes. Mineral carbonation is a set of natural processes that can be geo-engineered to operate faster and in desired locations. It can be applied in direct air capture and point-source capture scenarios. Mineral carbonation's principal advantages over geological carbon storage are the permanence of carbonates over millions of years (which reduces monitoring costs) and the potential to use large volumes of waste or low-value materials as sorbents (produced brines and fly ash, for example). Disadvantages include the embodied carbon of excavating and moving sorbents, the low carbon-to-sorbent ratios achievable, and environmental problems like the generation of rock dust and the release of toxic metals. The different mineral carbonation approaches available in West Virginia are compared qualitatively in Figure E.1.

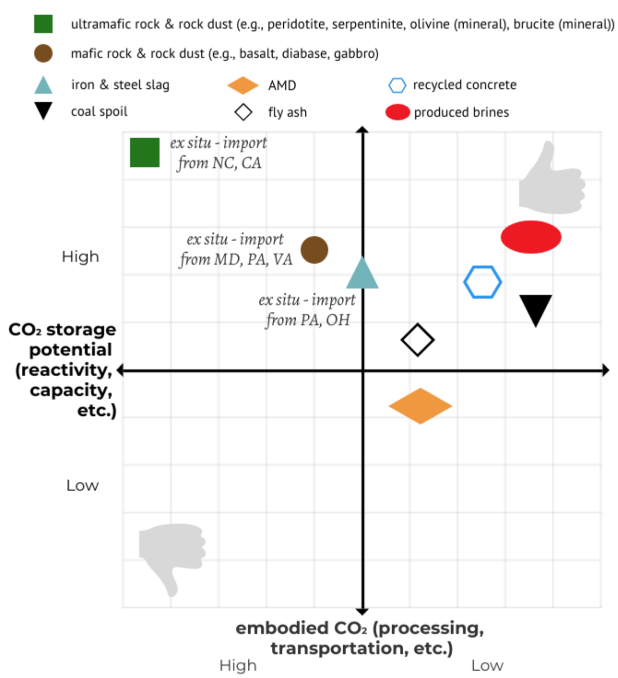

Figure E.1 Mineral Carbonation Approaches in West Virginia (West Virginia University, 2022)

Rock and Mineral Sorbents

West Virginia does not host significant resources suitable for mineral carbonation, but some neighboring states do. Calcium and magnesium-rich *mafic* rocks exist at the surface in a belt through central Pennsylvania, Maryland, and central Virginia, where they are quarried extensively for construction material. Industrial sources for very magnesium-rich *ultramafic* rocks, the optimal material, are limited to North Carolina and California. Both states have potential for *ex situ* mineral carbonation, where the rocks are quarried, crushed, and then either applied to large areas of land for direct air capture or concentrated in reaction cells at point sources. Of these two applications, concentration in reaction cells allows for higher temperatures and CO_2 pressures to enhance mineralization, though at the cost of increased energy use. However, compared to the industrial waste alternatives already available, neither approach is likely to be viable in West Virginia due to the costs of importing materials.

Industrial Waste Sorbents

Solid and liquid waste generated due to mining and large-scale industrial operations such as coal-fired power plants, cement plants, steelworks, and the oil shale industry are increasing annually and are harmful to the environment. Many of these materials are strongly alkaline, making them useful chemical reactants with CO_2 to produce carbonate minerals, for example steel slag. Moreover, acid mine drainage and fly ash have potential as secondary sources for Critical Minerals (CM) and Rare Earth Elements (REE). Carbon mineralization accompanied by the recovery of CMs and REEs from these wastes is an attractive venture; however, the technology to implement such a strategy is still underdeveloped. The key limitation is that the ‘net’ carbon storage potential and CM/REE extraction potential from these waste products is unknown. Therefore, there is a critical need to 1) develop strategies to evaluate and enhance the carbon storage potential of solid mining wastes and waste streams; 2) improve the release and recovery of CM/REEs from these waste materials; and 3) develop technologies to implement carbonate and CM recovery from lab to field scale.

Appendix F: West Virginia's Bioenergy with Carbon Capture & Storage (BECCS) Sequestration Potential

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Methods

Feedstocks

The mass of biomass feedstocks in West Virginia was quantified using an interactive online tool developed by the Department of Energy as part of their 2016 Billion Ton Report (DOE, 2016). The online tool considered the production of three categories of biomass feedstocks: forestry (whole-tree biomass and logging residues), agriculture (energy crops and crop residues), and other wastes (municipal solid waste, secondary crop residues, and manure). Two scenarios were modeled for each feedstock—a "low" scenario and a "high" scenario (Table F.1). Only timberland was considered in the forestry model (forestland was excluded) (DOE, 2016). The model calculated the mass of biomass feedstocks for 2017, 2022, 2025, 2030, 2035, and 2040. A linear regression model was then used to estimate the mass for 2050. The cumulative mass between 2022 and 2050 of each of the three feedstocks was calculated by multiplying the 2022 value by 1.5, the 2025 value by 4, the 2030 value by 5, the 2035 value by 5, the 2040 value by 7.5, and the 2050 value by 5.

By assuming that 49% of the biomass was carbon and accounting for the molecular weights of carbon (12) and carbon dioxide (44), in accordance with Getting to Neutral methods, the mass of biomass was converted to carbon dioxide equivalents (LLNL, 2020).

Table F.1. Model Input Conditions for Low and High scenarios for Forestry, Agriculture, and Other Wastes

	Low	High
Forestry	$40/dt, moderate housing, high energy demand	$80/dt, moderate housing, low energy demand
Agriculture	$40/dt, 1% yield increase	$80/dt, 3% yield increase
Other Wastes	$40/dt	$80/dt

Biomass Treatment Processes

The effectiveness of biomass treatment processes to capture carbon in West Virginia was quantified using methods similar to those in Chapter 4 of the Getting to Neutral report produced by the Lawrence Livermore National Laboratory (LLNL, 2020). Biomass conversion technologies include pyrolysis, gasification, anaerobic digestion, torrefaction, and hydrothermal liquefaction. Feedstocks may be better suited to some technologies over others due to their moisture and cellulose content (LLNL, 2020). For example, pyrolysis is not used to treat municipal solid waste. The technologies also capture carbon at different efficiencies. For example, the LLNL reports that 83 million out of 100 million tons of CO_2 could be captured per year using gasification to hydrogen, whereas 42 million tons could be captured via fast pyrolysis to liquid fuels (LLNL, 2020). However, the cost of gasification could be almost twice that of pyrolysis.

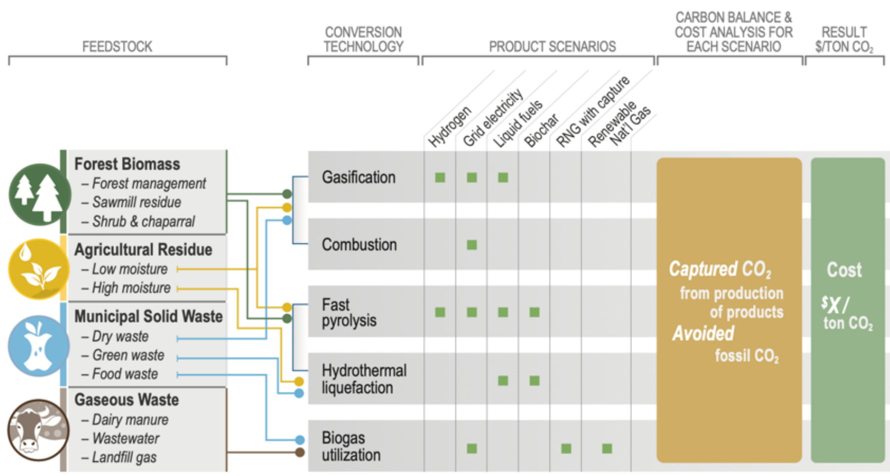


Figure F.1. Diagram Linking Biomass Type to Conversion Technology (LLNL, 2020)

Results and Discussion

Feedstocks

The projected mass of the biomass feedstocks in West Virginia and the United States is shown in Table F.2. The total feedstocks are projected to more than double in West Virginia between 2017 and 2050. The largest gains were from agriculture due to projected yield increase, due in turn to future biomass crop breeding and enhanced management practices (DOE, 2009). Those in the “other wastes” category remained relatively steady for both West Virginia and the United States.

The projected carbon dioxide removal in West Virginia from the three feedstocks was 1.5-5.3 million tons in 2022 and 3.3-15.9 million tons in 2050 (Table F.3).

Biomass Treatment Processes

Two biomass treatment processes were considered: direct biomass combustion to electricity (traditional BECCS) and Gasification with F-T Synthesis to Liquid Fuels. For electricity production, the projected carbon dioxide sequestration in West Virginia was 1.0-3.8 million tons in 2022 and 2.3-11.4 million tons in 2050. For liquid fuel production, the projected carbon dioxide sequestration was 0.8-3.1 million tons in 2022 and 1.9-9.4 million tons in 2050. The values were calculated under the assumption that electricity production would capture 76%, 69%, and 60% of the available carbon dioxide in forestry, agriculture, and other waste, respectively, while liquid fuel production would capture 61%, 58%, and 49%, respectively (Getting to Neutral).

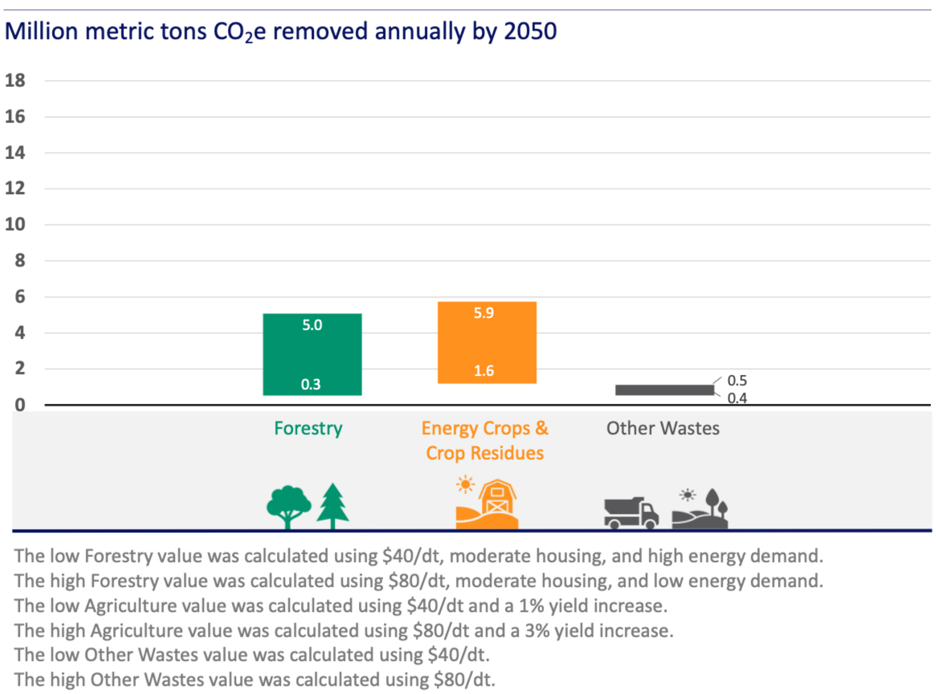


Figure F.2. West Virginia’s Technologically Enhanced Natural Annual Carbon Sequestration Potential: Bioenergy to Electricity with Carbon Capture & Storage (BECCS), by 2050 (West Virginia University, 2022)

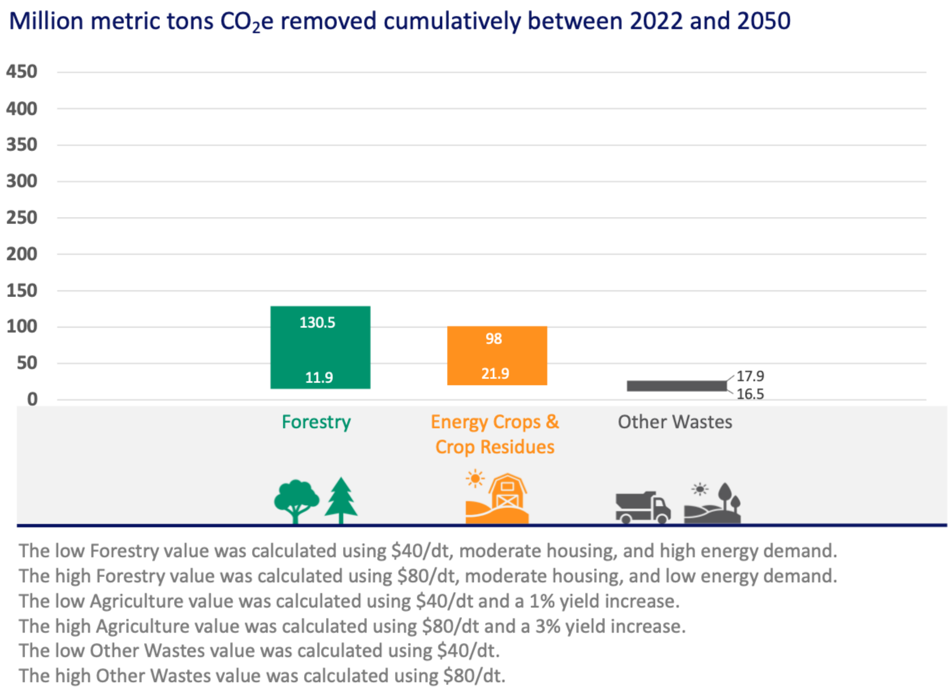
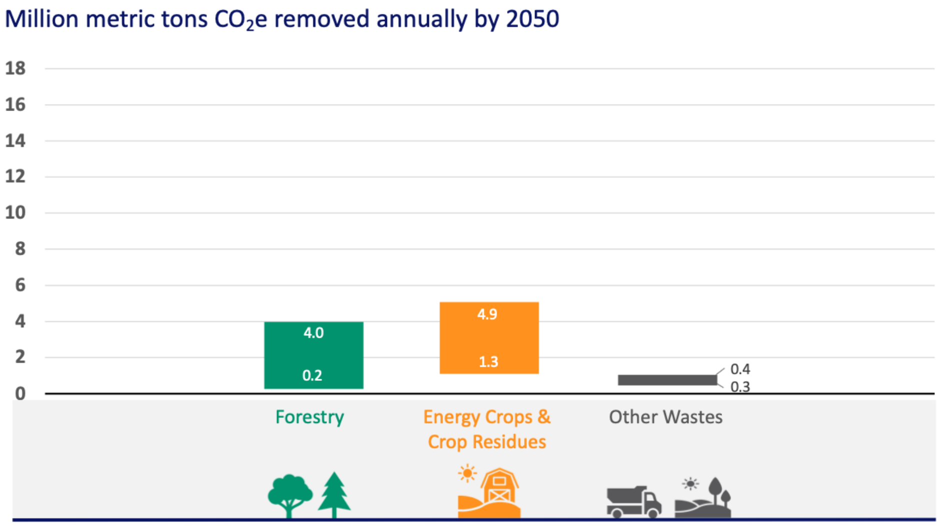


Figure F.3. West Virginia's Technologically Enhanced Natural Cumulative Carbon Sequestration Potential: Bioenergy to Electricity with Carbon Capture & Storage (BECCS), 2022-2050 (West Virginia University, 2022)



The low Forestry value was calculated using $40/dt, moderate housing, and high energy demand.
The high Forestry value was calculated using $80/dt, moderate housing, and low energy demand.
The low Agriculture value was calculated using $40/dt and a 1% yield increase.
The high Agriculture value was calculated using $80/dt and a 3% yield increase.
The low Other Wastes value was calculated using $40/dt.
The high Other Wastes value was calculated using $80/dt.

Figure F.4. West Virginia's Technologically Enhanced Natural Annual Carbon Sequestration Potential: Bioenergy to Liquid Fuels, by 2050 (West Virginia University, 2022)

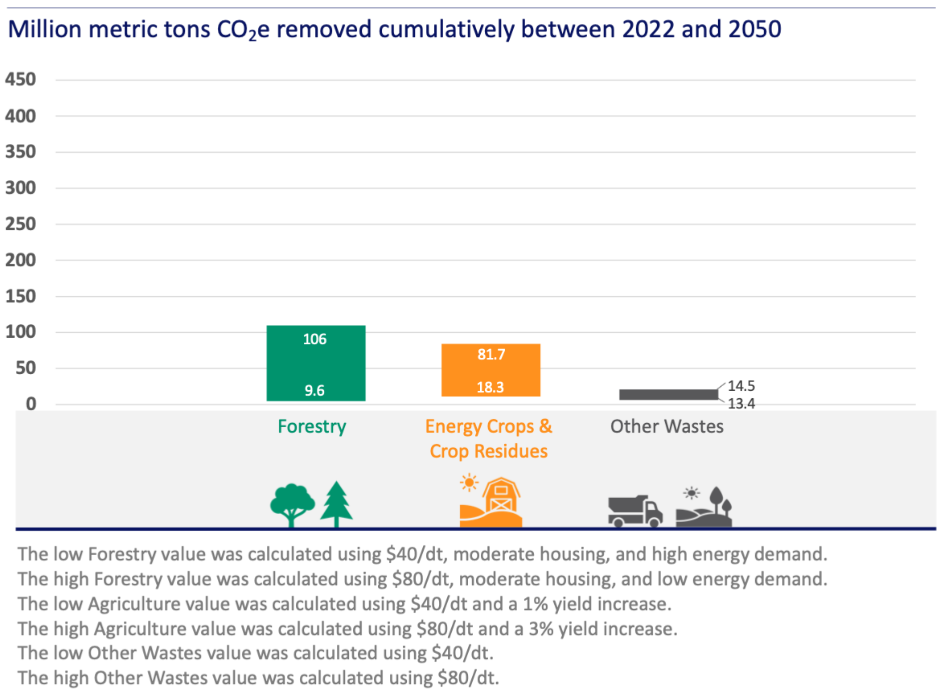


Figure F.5. West Virginia's Technologically Enhanced Natural Cumulative Carbon Sequestration Potential: Bioenergy to Liquid Fuels, 2022-2050 (West Virginia University, 2022)

Table F.2. Projected Mass of the Three Biomass Feedstocks (Forestry, Agriculture, and Other Wastes) in West Virginia in Millions of Dry Tons per Year

	Total															
	2017		2022		2025		2030		2035		2040		2050		2022-2050	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
US	160	347	166	596	166	700	181	888	194	997	225	1211	241	1572	6501	32774
WV	0.7	2.7	0.8	2.9	0.8	4.3	1.0	5.6	1.3	6.0	1.6	6.8	1.8	8.9	41.6	191.2
WV (%)	0.5%	0.8%	0.5%	0.5%	0.5%	0.6%	0.5%	0.6%	0.7%	0.6%	0.7%	0.6%	0.8%	0.6%	0.6%	0.6%

Table F.3. Projected Carbon Dioxide Removal Equivalents from Three Biomass Feedstocks (Forestry, Agriculture, and Other Wastes) in West Virginia in Million Tons per Year

	Total															
	2017		2022		2025		2030		2035		2040		2050		2022-2050	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
US	287	623	298	1071	298	1258	324	1596	349	1791	404	2176	434	2824	11680	58884
WV	1.3	4.8	1.5	5.3	1.5	7.7	1.7	10.1	2.4	10.8	2.9	12.3	3.3	15.9	74.7	343.5

Table F.4. Electricity Values: Direct Biomass Combustion to Electricity (Traditional BECCS): Gasification Scenario 4 from Three Biomass Feedstocks (Forestry, Agriculture, and Other Wastes) in West Virginia in Million Tons per Year

	2017		2022		2025		2030		2035		2040		2050		2022-2050	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
US	186	438	197	776	198	918	218	1173	237	1320	279	1611	302	2100	7932	43398
WV	0.9	3.5	1.0	3.8	1.0	5.6	1.2	7.3	1.6	7.7	2.0	8.8	2.3	11.4	50	246

Table F.5. Fuel Values: Gasification w/ F-T Synthesis to Liquid Fuels: Gasification Scenario 1 from Three Biomass Feedstocks (Forestry, Agriculture, and Other Wastes) in West Virginia in Million Tons per Year

	Total															
	2017		2022		2025		2030		2035		2040		2050		2022-2050	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
US	151	349	158	608	158	716	174	912	188	1025	220	1247	238	1622	6299	33689
WV	0.7	2.9	0.8	3.1	0.8	4.6	1.0	5.9	1.3	6.3	1.6	7.2	1.9	9.4	41	202

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Appendix G: Direct Air Carbon Capture (DAC) Potentials In Southern West Virginia

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Growing interest in the deployment of carbon dioxide removal (CDR) technologies is driving interest in direct air capture (DAC) of carbon dioxide. To better guide policymakers and to help provide some context for this discussion, an evaluation of DAC potentials, focused on reuse of former minelands in southern West Virginia, was performed. Overall, 66 sites, each with a footprint larger than 100 acres, were identified in 5 southern counties (Boone, Logan, Mingo, Raleigh, and Wyoming), overlying potential storage reservoirs of 30 metric tons. While further research and development is needed, this analysis highlights strong potential for the deployment of DAC facilities in these southern coalfields. Note that this analysis does not consider whether or not DAC is a better option relative to responding to climate change than alternatives such as renewable energy or commercial or residential uses in regions where there are few options for flat land that is not in a floodplain.

A more detailed description of our workflow, the results of our analysis, and further discussion are included below.

Direct Air Capture

Direct air capture (DAC) technologies are discussed in greater detail earlier in this document. The primary strength of DAC relative to this analysis is location flexibility. Provided that sufficient area is available for the surface DAC facility, the facility can be located where there is adequate CO_2 storage. This enables DAC to be sited independently of considerations for CO_2 pipeline construction or proximity to other large point-source emissions sources (such as coal fired power plants). While location selection is flexible, land area is a significant consideration. For the purposes of this analysis, a minimum site size of 100 acres (~0.4km^2) was used as a screening criterion, based on general sizing requirements found in the literature (Breyer et al, 2020; Fasihi et al, 2019; Socolow et al., 2011; Johnston et al, 2003). In addition to the minimum size, these facilities can be considered analogous to chemical processing facilities and cannot be constructed on steep terrain. This limitation was also used as a screening criterion in this analysis. No specific performance analysis relative to DAC technology type (i.e., solid sorbent vs. liquid solvent) was performed, but general performance estimates from the literature for a 1Mt/y capture project were used to estimate land requirements.

Regional Focus

The target region of study was identified using the conceptual model illustrated in Figure G.1. The procedure used for this project was performed using the ESRI ArcMap 10.5.1 GIS software suite. All input data to the GIS platform was classified as vectorized data and required no additional plugin packages, pre-analysis editing, or other external software. The projection used for all GIS-related processing was the NAD1983 global projection. For a local projection, NAD83 UTM 17N is highly recommended for the spatial extent of West Virginia.

All data from this project were selected using attribute table properties and SQL code statements. A combination of clip, intersection, and buffer geoprocessing procedures were performed from SQL selections to create overlay map layouts. This procedure retains all geospatial data from the attribute table per vector polygon, so no attribute data was lost through layer iterations. To ensure the validity of spatial extent (acreage), for all mine site layers, a separate, projection-based measure of total acreage per mine site polygon was included. This additional attribute table column may be encountered within the spatial data and was not produced by the original geospatial authors of the data but was calculated independently.

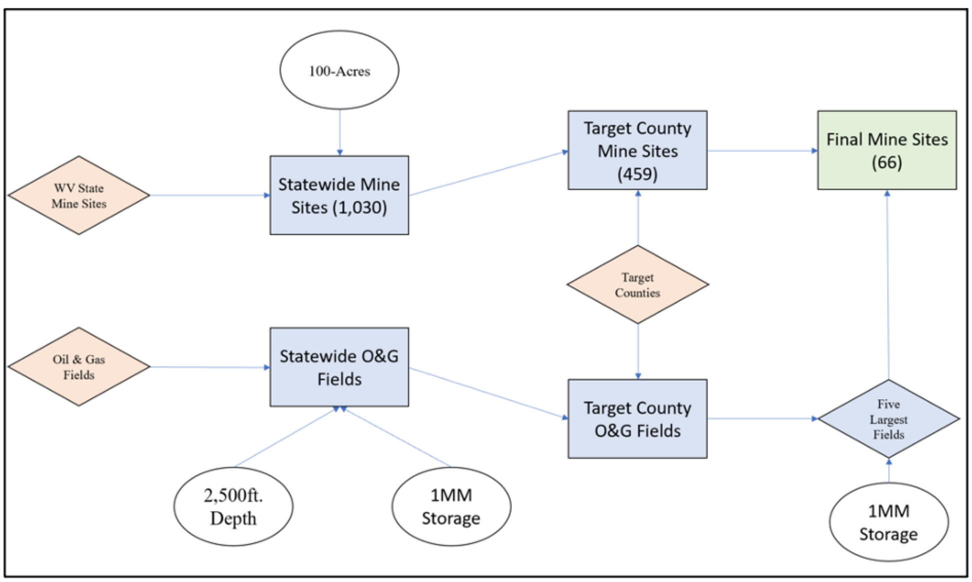
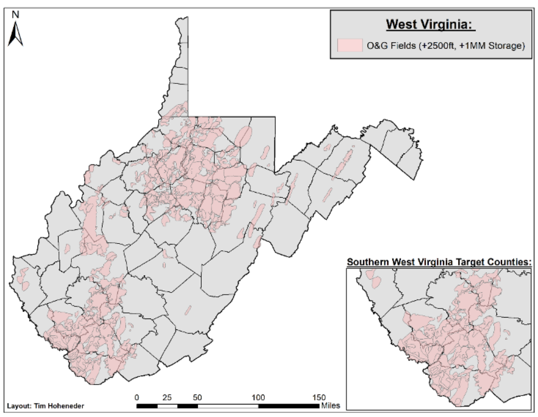


Figure G.1. Conceptual Model for Identification of Potential DAC Facility Locations (West Virginia University, 2022)

Storage Feasibility

Oil and gas field geospatial data were provided through data from Jessica Moore of the West Virginia Geological Survey. Fields provided were those residing at a depth of greater than 2,500ft. and included at least 1 million metric tons of minimum storage for the field unit (Lewis et al. 2019). This initial query returned a total of 280 fields meeting the two criteria. Figure G.2 shows the location of fields deeper than 2,500 ft with storage capacities greater than 1 Mt. These fields typically occur as “stacked” reservoirs, with different target reservoirs occurring at different depths (Figure G.3). This stacking leads to higher cumulative storage potentials at a single surface location through the utilization of multiple target formations in the subsurface.



CO2 Storage Field Characteristics

Total Fields >1MT capacity	280

Figure G.2. Map of Potential CO_2 storage fields in West Virginia, 1Mt Capacity or Greater (West Virginia University, 2022)

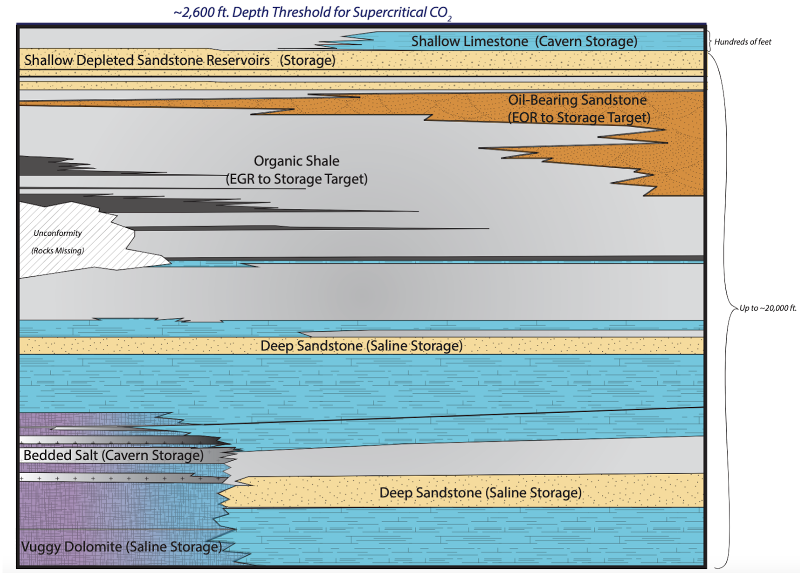
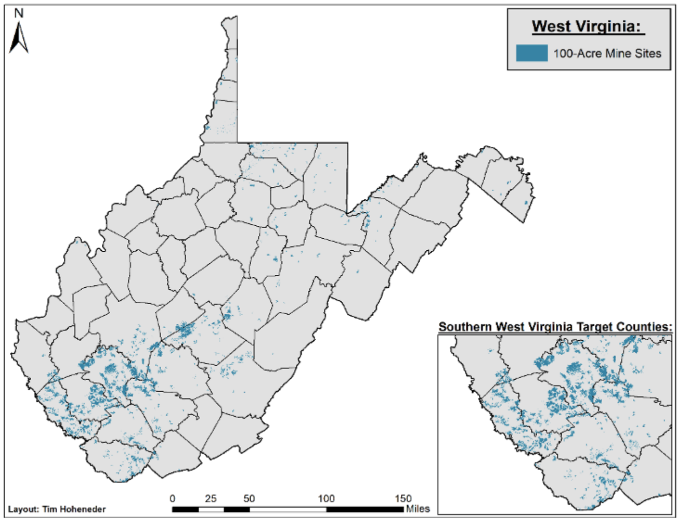


Figure G.3. Stacked Storage in the Appalachian Basin (West Virginia Geological & Economic Survey, Personal Communication, 2022)

Former Mine Sites

Revitalization of former mine sites is essential because they are often in, or adjacent to, persistent poverty communities, as reflected in the Interagency Working Group report on coal-impacted communities. There are thousands of acres of former minelands in West Virginia, and the state has the highest number of surface mines in Appalachia. As a screening tool, this assessment sought to find surface acreage of at least 100 acres (0.4 km^2). The first iteration of data processing included placing all surface mining permitted sites in the state of West Virginia into the GIS server. All mine site data were retrieved from the West Virginia Department of Environmental Protection GIS server. Secondly, mine sites were clipped at the statewide extent to only those listed as having a total area greater than 100 acres per the attribute table field "acres_curr." This query returned 1,030 sites across the state meeting the 100-acre or greater threshold. Figure G.4 shows the location of surface mine sites with extents greater than 100 acres in West Virginia.



Surface Mine Site Characteristics	
Total Fields >100A	1,030

Figure G.4. Surface Mine Sites >100 Acres (West Virginia University, 2022)

Detailed Analysis

In the next stage of the analysis, the intersection of 100-acre sites and >1 Mt storage formations was examined. Figure G.5 depicts this intersection. This figure highlights a key finding of this analysis: while surface mine sites exist across West Virginia and suitable storage targets also exist in a relatively broad area of West Virginia, the intersection of these attributes is much more highly concentrated in the southern West Virginia coalfields region. Additionally, while northern West Virginia also has potential storage resources, there is likely to be increased competition for these resources as CO_2 storage requirements increase. For example, deployment of “blue” hydrogen systems would necessitate CO_2 storage in the production of hydrogen. Recent DOE studies have identified northern West Virginia/southwestern Pennsylvania as a likely target for hydrogen deployment, which will drive demand for CO_2 storage options in these areas.

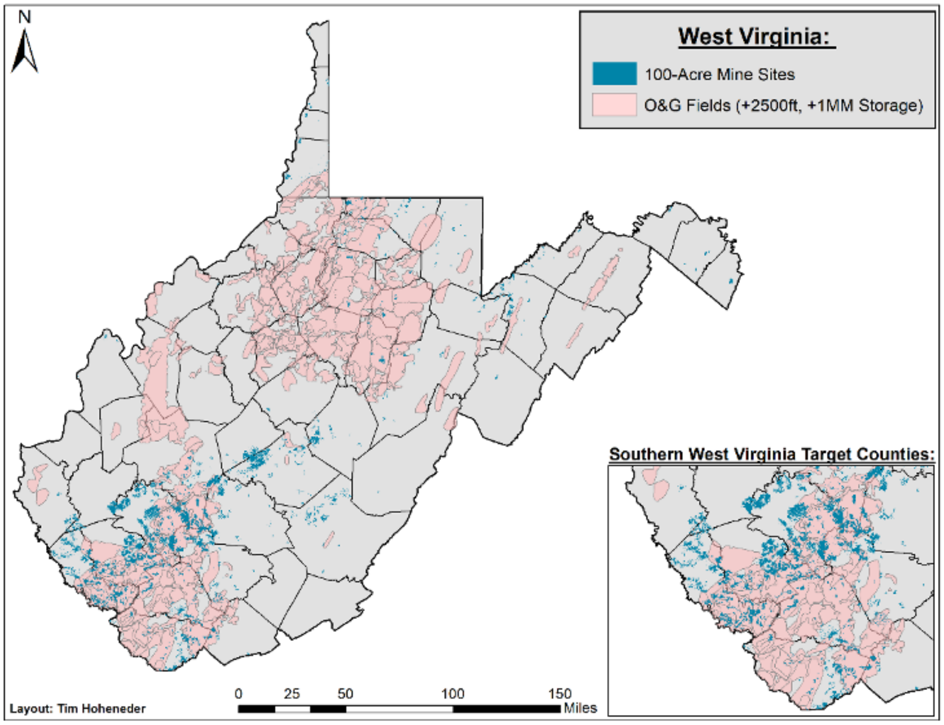


Figure G.5. Overlap of 1 Mt Storage Formations and Surface Mine Sites >100 Acres (West Virginia University, 2022)

Concentrating on the southern coalfields region, a subset of target counties was identified based on a high concentration of surface mine sites and suitable storage. Six counties were selected for further evaluation: Boone, Logan, McDowell, Mingo, Raleigh, and Wyoming.

In this reduced set, analysis returned 60 oil and gas fields with storage greater than 1 Mt and 459 mine sites >100 acres within the southern target counties. Figure G.6 illustrates the intersection of these two data sets, and illustrates that while there are ample opportunities for a potential DAC project, there are large mine complexes that are either outside of feasible storage targets or are on the border of these targets, which raises the technical risk relative to the confinement and boundaries of the target formation.

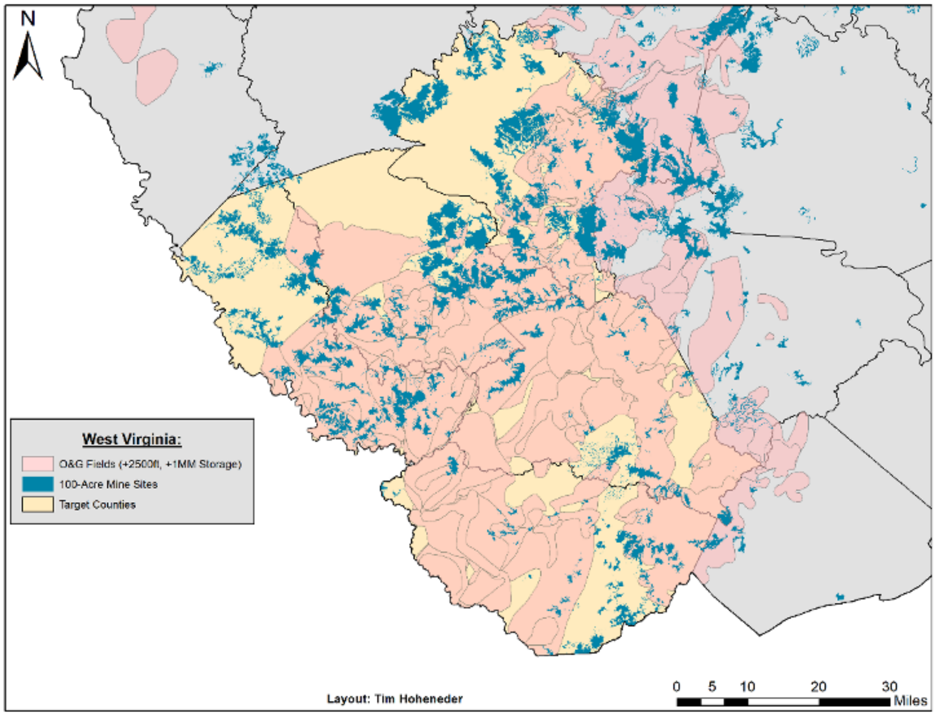


Figure G.6. Illustration of 100-acre Mine Sites Overlying 1 Mt Storage Facilities, Focused on Counties for Further Evaluation (West Virginia University, 2022)

These results suggest that a more aggressive screening criteria could be used in further narrowing potential sites for future evaluation. Given the larger number of potential surface sites, CO_2 storage volume was chosen as the more effective method for this down selection. Additionally, capital cost estimates for DAC systems vary, but estimates by McQueen et al (2021) are in the $400 per ton per annum range, depending on energy source cost and technology used. Assuming a $500,000,000 overall capital cost for installation, the lifetime of the facility should be significant, allowing time to recoup the cost of construction. Assuming 1 Mt/y capture and a 30-year life, we target storage locations capable of 30 Mt of CO_2 storage based on current estimates.

Five large fields contain minimum storage of over 30 Mt in this target region. Table G.1 provides some description of these target formations.

Table G.1. Target CO_2 Storage Formations (West Virginia University, 2022)

Field Name	Depth (ft)	Thickness (ft)	Minimum Storage (MM)
Mann-Oceana	2994	37	61,751,007.00
Hopkins Fk-Jarrolds	3075	67	58,156,399.00
Magnolia	2709	37	50,113,010.00
Hopkins Fk-Jarrolds	2732	51	39,436,547.00
McGraw	2932	35	38,726,080.00

Finally, mine sites were restricted to those only intersecting the surficial footprint of these large storage fields. This produced a final product of 66 mine sites.

Table G.2 provides a breakdown of those sites. More interestingly, a significant number of sites are in excess of 400 acres, which would provide further feasibility if on-site energy production for solvent/sorbent regeneration was desired or if other design considerations for DAC equipment spacing were required. Recent National Academies studies (2018) find that land use requirements increase when accounting for these other demands (e.g., power generation, sufficient spacing between units).

Table G.2. Mine Sites Overlying 30 Mt Storage (West Virginia University, 2022)

Acres	Number of Mine Sites
100+	66
400+	15
800+	5
1,200+	2
Average Acres/Site	426.69

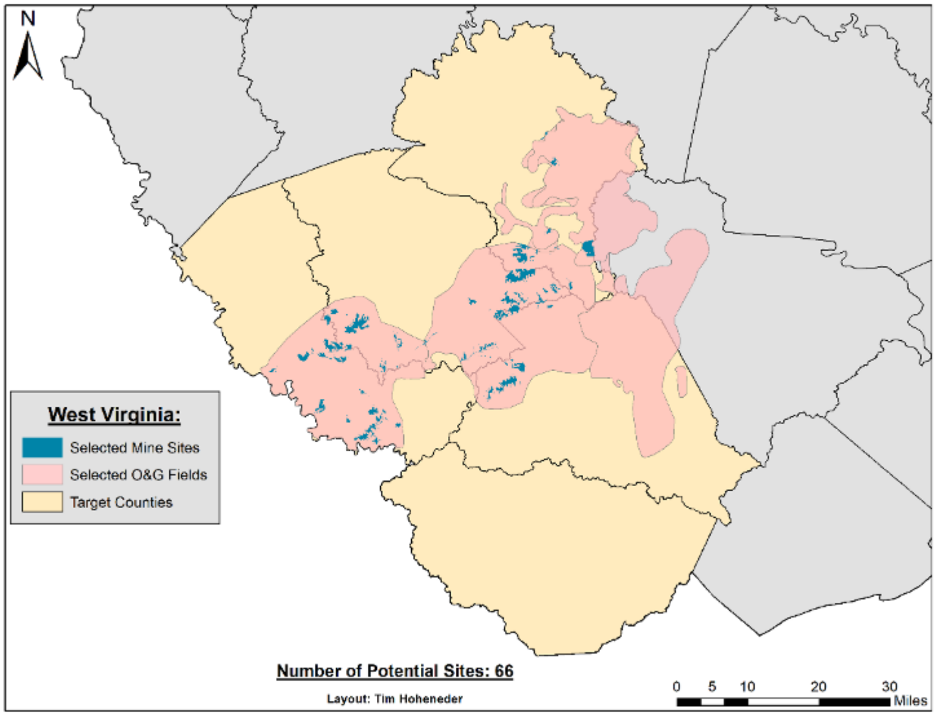


Figure G.7. Map of 66 Potential Sites for Carbon Dioxide Storage in Southern West Virginia (West Virginia University, 2022)

Conclusions

Opportunities for DAC appear to exist in the southern coalfields. Using screening criteria of at least 100 acres (0.4 km^2) and 30 Mt of storage, 66 potential surface sites were identified in Boone, Logan, Mingo, and Raleigh Counties. No intersection of 30 Mt storage and 100-acre sites were found in McDowell County. Further characterization is required to better define any potential project, including definition of landowner and identification of any potential bonding or liability issues associated with those sites; identification of potential energy sources for solid sorbent or liquid solvent regeneration (i.e., thermal or electrical energy); and more detailed site planning for the optimal layout and deployment of a DAC facility.

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Appendix H: Geologic CO_2 Storage Potential in West Virginia

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Some CDR options including DAC and BECCS require that the CO_2 be utilized or stored if they are to impact climate change. In West Virginia, the CO_2 can be stored in deep subsurface geological formations for permanent geological storage.

Deep Subsurface Permanent Storage Options

The basic requirements that a geologic formation must have for successful subsurface CO_2 storage are (1) a high storage capacity; (2) to be sealed so that the injected CO_2 cannot escape; and (3) a depth of more than 800 m (critical point of CO_2). Based on the observations from engineered and natural analogs, it is estimated that the CO_2 fraction retained in appropriately selected and managed geological reservoirs is likely to exceed 99% over 1,000 years (Intergovernmental Panel on Climate Change, 2005).

The National Energy Technology Laboratory (2016) estimates the total subsurface carbon dioxide storage potential in different geological formations in West Virginia to be between 17.49 and 29.61 billion metric tons. The DOE Carbon Atlas provides low, medium, and high estimates of the carbon storage capacities of different geological formations (Table H.1).

Table H.1. Storage Capacity of Different Geological Formations in West Virginia (adapted from National Energy Technology Laboratory, 2016)

	Storage Capacity in Billion Metric Tons		
	Low	Medium	High
Oil and Natural Gas Reservoirs	5.93	9.84	18.05
Unmineable Coal Seams	0.37	0.37	0.37
Saline Formations	11.9	11.9	11.9
Total Storage Resource	17.49	21.40	29.61

However, these are potential resource estimates that need to be proven by further detailed site characterization studies. There is also a need to identify storage targets that are well characterized from a safety and leakage perspective, proximity to significant point sources of CO_2 emissions, available pipeline and well infrastructure, socioeconomic impact, etc.

West Virginia has a long history of oil and gas development going back to the 19th century. The depleted oil and gas fields are ideal targets for CO_2 sequestration because 1) the reservoirs are well characterized in terms of depth, size, and resource storage capacity; 2) the reservoirs have well-defined seals that will prevent CO_2 leakage from the reservoir after it is injected; and 3) the sequestration process can produce value-added residual oil and gas that will be carbon negative. During the last decade, rapid shale gas development in the northern part of the state has also opened up the possibility of utilizing these hydraulically fractured shale reservoirs as target reservoirs for CO_2 sequestration. The location, extent, and approximate sequestration potential of all the oil and gas fields in the state, along with the power plant locations symbolized by their 2013 CO_2 emissions, are depicted in Figure H.1.

Unmineable coal seams are defined as coal seams that are too deep or too thin to be economically mined. Coals can also provide an excellent storage target for CO_2 because CO_2 can potentially displace the methane adsorbed on the coal (2-13 molecules of CO_2 are adsorbed for each molecule of methane released). However, issues related to the swelling of coal can limit the use of coal seams for sequestration.

The other available geological targets for CO_2 sequestration are saline formations which are units of porous rock saturated with highly saline water or brine. The saline formations have enormous potential for sequestration because they are much more extensive than oil/gas formations and coal seams. However, the major limitations of utilizing saline formations are that 1) they are not well characterized in terms of their size, capacity, and leakage potential and 2) various physical mechanisms, reaction pathways, and time scales of reactions involved in CO_2 trapping are not well modeled. Nevertheless, the CO_2 storage capacity of saline formations in West Virginia is estimated to be very high. However, these formations will need to be fully characterized in terms of their temperature, pressure, depth, capacity, chemical reactions, and flow paths.

Shallow Subsurface Temporary Storage Options

In addition to deep subsurface permanent CO_2 storage options, West Virginia also has abandoned mine lands that can be targeted for the temporary storage of CO_2 produced as a by-product of various carbon capture technologies such as direct air capture and Green H_2 production. These lands include thousands of unreclaimed surface mines abandoned prior to the Surface Mining Control and Reclamation Act of 1977 (Figure H.2) and underground natural gas storage fields (Figure H.3). The 31 gas storage field sites represent 6% of the nation's total natural gas storage capacity, which amounts to about 531 billion cubic feet of natural gas (U.S. Energy Information Administration, 2022).

To develop the CO_2 sequestration projects and business opportunities in West Virginia, there is a need to identify a demonstration site based on rating criteria that include

- proximity to power plants (if we are targeting CDR from point source emissions)
- availability of deep oil and gas reservoir (for permanent CO_2 storage) or abandoned mine lands/gas storage fields (for temporary CO_2 storage and utilization)
- proximity to the available infrastructure of transport, roads, pipes, and wells
- socioeconomic impact on the fossil fuel based rural communities

After the site has been selected, the remaining challenges that will need to be addressed are 1) comprehensive geological, geochemical, and geomechanical characterization of formations in which CO_2 will be injected; 2) obtaining required permits; 3) maintaining the supply of CO_2; 4) assessing the economic viability of the sequestration operation; and 5) gaining public confidence in this new technology.

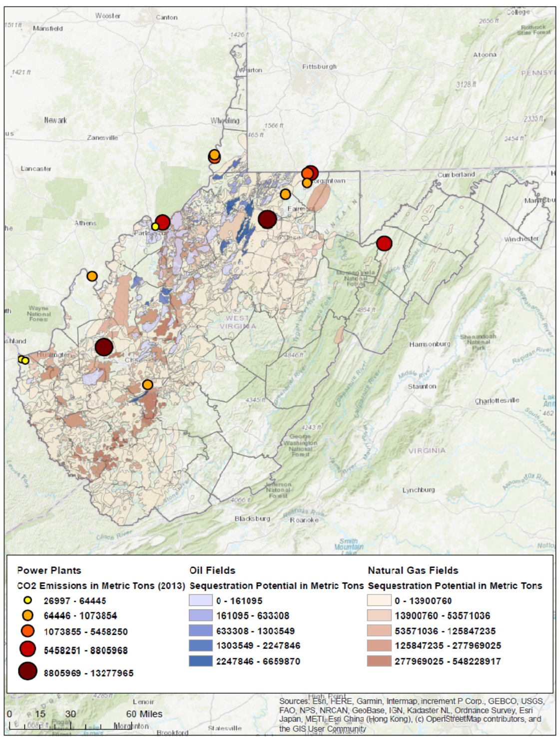

Figure H.1. Major Oil and Gas Fields, with CO_2 Storage Potential, in West Virginia (West Virginia University, 2022) *Map showing the spatial extent of all the major oil and gas fields in the state along with their approximate CO_2 storage (sequestration) potential. This map also shows the* *location of major power plants in relation to these oil and gas fields. The size of the power plant is proportional to its total CO_2 emission in 2013.*

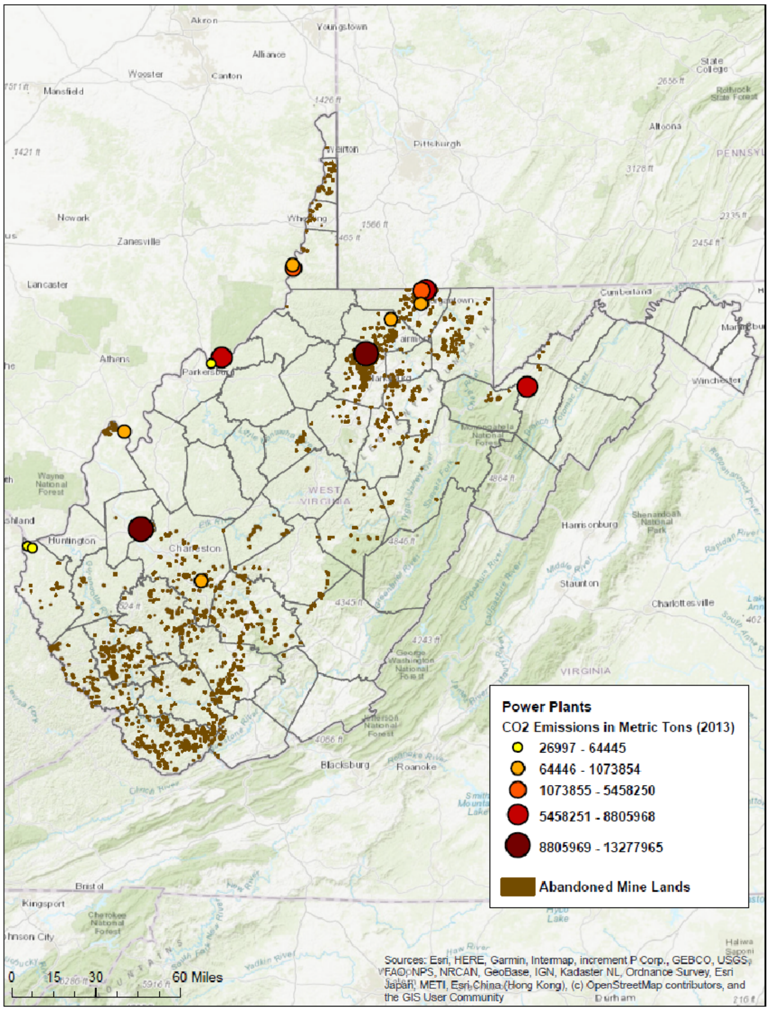

Figure H.2. Abandoned Mine Lands, Relative to Major Power Plant Proximity, in West Virginia (West Virginia University, 2022) *Map showing the spatial extent of abandoned mine lands in the state in relation to the location of major power plants. The size of the power plant is proportional to its total CO_2 emission in 2013.*

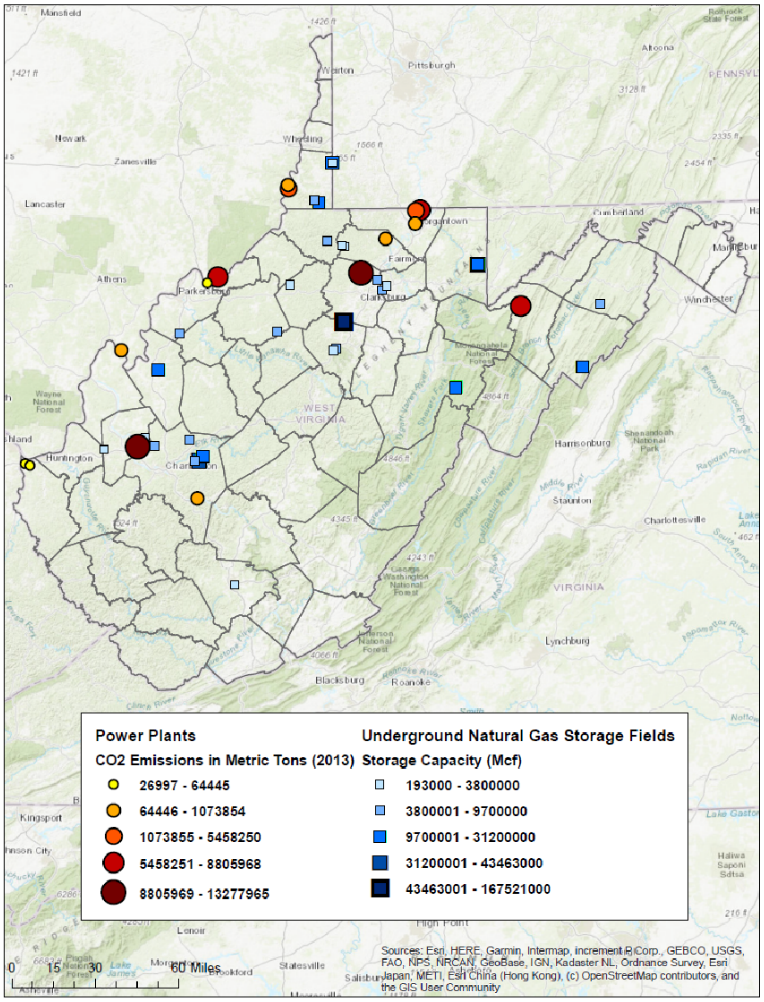

Figure H.3. Underground Natural Gas Storage Fields, Relative to Major Power Plant Proximity, in West Virginia (West Virginia University, 2022) *Map showing the location of underground natural gas storage fields in the state in relation to the location of major power plants. The size of the power plant is proportional to its total CO_2 emission in 2013.*

References

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Appendix I: Carbon Sequestration Options Investment

To develop the potential job creation from the different options for carbon sequestration, the policymaker guide authors needed to estimate how much capital investment was needed for each option. To determine the investment required, we used the cost estimates from the Lawrence Livermore National Laboratory report Getting to Neutral: Options for Negative Emissions for California for the gasification scenarios in 2025 and 2045. In the case of natural solutions, the cost estimates remain the same for both years. For both bioenergy and direct air capture, technological learning is assumed to take place, causing the costs to decrease.

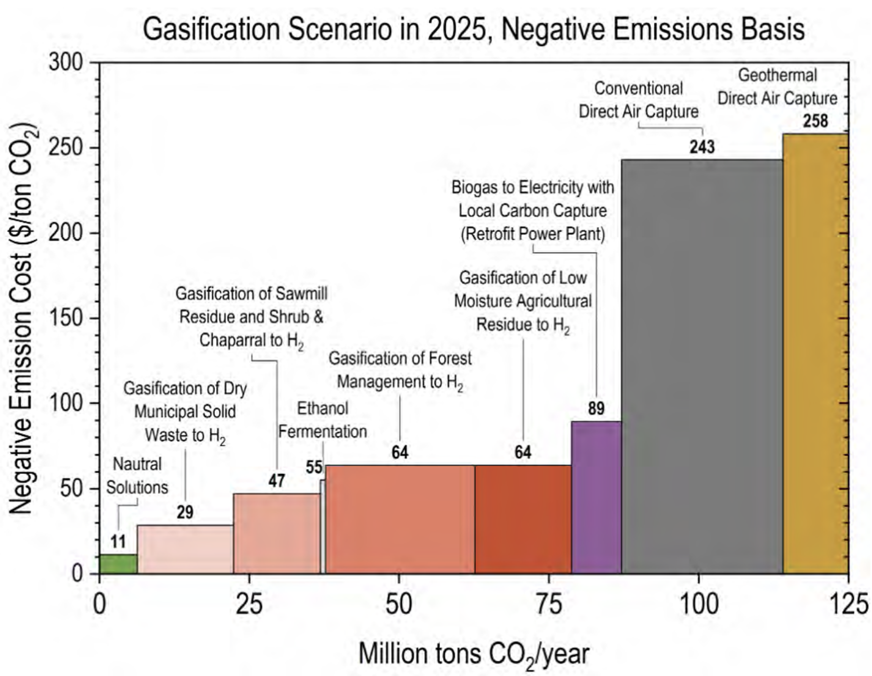

Figure I.1. Total Cost Curve for Gasification Scenario, 2025, Negative Emissions Basis (Lawrence Liverpool National Laboratory, 2019)

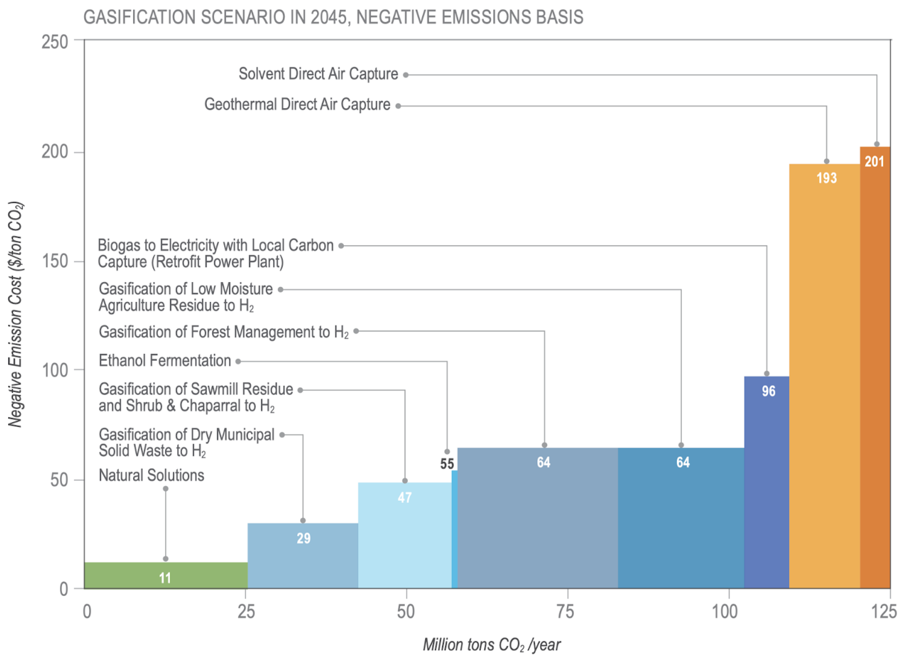

Figure I.2. Total Cost Curve for Gasification Scenario, 2045, Negative Emissions Basis (Lawrence Livermore National Laboratory, 2019)

Table I.1 outlines the annual carbon capture potential for natural (total in green), bioenergy (total in yellow), and direct air capture (total in aqua) options as developed in this guide for West Virginia. The gold vertical bar provides a comparison between the West Virginia and California estimates to check the feasibility given the nature and size of each state.

For the WV Lower LLNL 2025 estimate, we multiplied the WV Lower Bound CDR potential by the LLNL 2025 cost estimate to determine the annual million dollars of investment. For the WV Upper LLNL 2045 estimate, we multiplied the WV Upper Bound CDR potential by the LLNL 2045 cost estimate. This provided a range of investment estimates.

These estimates were then provided to the WVU Bureau of Business and Economic Research to estimate, in turn, the potential jobs that would be created in West Virginia if these investments were made.

Table I.1. Estimated Financial Investment for Natural, Bioenergy, and Direct Air Capture Activities in West Virginia (West Virginia University, 2022)

	WV Lower Bound CDR (MmtCO2e annually by 2050)	WV Upper Bound CDR (MmtCO2e annually by 2050)	WV Average Estimate Carbon Captured (MmtCO2e annually by 2050)	LLNL 2025 Cost Estimate ($/tonCO2e)	LLNL 2045 Cost Estimate ($/tonCO2e)	LLNL Average Cost Estimate ($/tonCO2e)	WV Lower * LLNL2025 (Annual Million $)	WV Middle Estimate (Annual Million $)	WV Upper * LLNL2045 (Annual Million$)
Natural	1.11	8.81	4.96	11	11	11	12.21	54.56	96.91
-Forest Management	1.05	5.87							
-Agriculture Management	0	2.6							
-Abandoned Mine Land Restoration	0.03	0.28							
-Wetland Restoration	0.03	0.06							
Biomass to Electricity	2.3	11.4	6.85	120	96	108	276	739.8	1094.4
- Forestry	0.3	5							
-Agriculture	1.6	5.9							
-Other Wastes	0.4	0.5							
Biomass to Fuel	1.8	9	5.55	55	55	55	99	305.25	511.5
- Forestry	0.2	4							
-Agriculture	1.3	4.9							

-Other Wastes	0.3	0.4							
Direct Air Capture	0	8	4	243	201	222	0	888	1608

One question that arose during our discussions was how this level of investment compared to past investments in West Virginia. The total annual investments from Table I.1 for CDR activities range from $12-$324 million in 2025 to $97-$1,267 million ($1.3 billion) in 2045. Box I.1 provides a list of major investments in West Virginia. The comparisons are challenging, as we do not have the annual investments nor forecasts to 2045, but the largest investments thus far are $500 million for a Proctor & Gamble plant in 2018 and $2.7 billion for Nucor's steel manufacturing facility in 2022.

Box I.1. Past Major Economic Infrastructure Investments in West Virginia

Toyota:

Invested over $1 billion since 1996 in its Buffalo, WV plant. Most recent investment came in 2021 with $240 million in modifications and additions to the Buffalo plant for use in hybrid vehicle transaxle manufacturing.

Blue Racer Midstream:

Owned by Dominion (VA) and Caiman Energy (TX), Blue Racer Midstream built a processing and fractionalization facility in Natrium (Marshall County) in 2013. The total investment for the project was ~$500 million.

MarkWest:

Over the last decade, Colorado-based MarkWest Energy has invested ~$900 million in natural gas plants in multiple counties. The largest is the Sherwood MarkWest plant in Doddridge county. According to the link below, the company has invested nearly $10 billion in the region.

ROXUL:

An insulation manufacturing subsidiary of Rockwool, this Denmark-based company invested $150 million in development of its Jefferson County manufacturing plant in 2018.

Proctor & Gamble:

Invested ~$500 million in infrastructure and development in Berkeley County in 2018. This is the largest P&G production site in the world.

Nucor Corporation:

North Carolina-based Nucor announced a $2.7 billion infrastructure investment in WV in 2022. The facility will be located in Mason County, and will be used as a state-of-the-art producer of sheet steel.

Appendix J: Potential Economic Impact of Carbon Remediation in West Virginia

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Introduction

In this briefing paper, we estimate the potential economic impact of carbon remediation efforts on the West Virginia economy. For this study, we consider the economic impact of the operation of carbon-reducing measures both through natural means—such as forest management and abandoned mine land restoration—and through the operation of biomass power production within the state. We estimate the economic impact in terms of output, employment, labor income, and select state and local tax revenue.

For this study, we assume that all expenditures from carbon remediation would result in new, additional spending in the state's economy. We also assume that workers at these operations will live in West Virginia and spend their income similarly to the average West Virginia resident. All data for this study were provided to the Bureau of Business and Economic Research (BBER) by the WVU Carbon Dioxide Removal Working Group and were not independently audited by the BBER.

To estimate the economic impact of carbon remediation, we apply a detailed model of the West Virginia economy that outlines how trade-flows among industries interact with key economic indicators such as employment, income, output, and tax revenue. The annual expenditures for carbon removal measures are referred to as the direct economic impact. However, the total economic impact of these activities is not limited to the direct impact, but also includes the secondary economic impacts accrued as those initial direct expenditures are re-spent across the state, generating a multiplier effect throughout the rest of the state's economy.

Natural Measures Impact

Figures provided to the BBER indicate that natural carbon remediation efforts could support between \$12.1 million and \$54.6 million of additional annual expenditures in the state of West Virginia. This wide range of expenditures reflects uncertainty surrounding the amount of carbon capture potential using these methods. Using national average employment ratios found in the IMPLAN economic model, this level of expenditure would support between 126 and 561 direct workers in the forest management industry.

Total economic impacts are shown in Table J.1. We estimate that the total economic impact of expenditures in support of natural carbon sequestration would be between \$18 million and \$81 million, with between \$6 million and \$27 million coming in secondary supplier industries. Total employment is expected to be between 200 and 892 workers, of which between 74 and 331 are estimated to come from secondary impacts. We estimate that the forest management spending will generate between \$8 million and nearly \$35 million in labor for workers in the industry and an additional $3 million to $12 million in secondary impacts, for a total labor income impact of between $10 million and nearly $47 million. Total potential tax revenue is estimated to range between just under $1 million and $4.3 million, depending on the scenario. Of this, between $700 thousand and $3 million would be paid directly by the forestry industry and its workers, with an additional approximately $300 thousand to $1 million coming from secondary sources.

Table J.1. Annual Economic Impact of Natural Carbon Sequestration Efforts

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	12.2–54.6	6.0–26.7	18.2–81.3
Employment (jobs)	126–561	74–331	200–892
Labor Income ($, millions)	7.8–34.8	2.7–12.0	10.5–46.9
Total Taxes ($, millions)	0.7–3.2	0.3–1.1	1.0–4.3

Note: Tax Revenue impact includes sales, personal income, property, and corporation net income taxes.

Biomass Power Plant Impact

Another potential avenue for West Virginia to participate in the carbon remediation economy would be with the operation of biomass power plants and other associated activities. Estimates provided to the BBER indicate that biomass power plants could generate between $276 million and $1.1 billion in annual operating expenditures in the state. Again, these numbers have considerable uncertainty based on the amount of annual carbon sequestration and the cost of biomass power generation. Though it is likely that biomass power would be spread across multiple sites in the state, to simplify the analysis we have represented these expenditures as a single large biomass plant located in the state of West Virginia.

Based on national average employment, the above projected biomass spending would support between 183 and 724 workers directly at the plant, with approximately $30 to $120 million in annual labor income (Table J.2). Including secondary industries, the plant would employ a total of between 746 and 2,960 workers, with 564 to 2,236 jobs coming from secondary impacts in the state. Total labor income for these workers is expected to be between $70 million and $277 million, including $39 million to $156 million in secondary industries.

We estimate that a biomass plant of this size would generate a total of between $446 million and $1.8 billion in annual economic activity in the state, of which between $170 million and $675 would come in secondary supplier industries. The plant would be expected to generate between $5 million and $19 million in state and local tax revenue annually, with another $4 million to $17 million coming in secondary impacts, for a total tax revenue impact of between $9 million and $66 million.

Table J.2. Annual Economic Impact of Biomass Power Plant Spending

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	276–1,094	170–675	446–1,770
Employment (jobs)	183–724	564–2,236	746–2,960
Labor Income ($, millions)	30–120	39–156	70–277
Total Taxes ($, millions)	5–19	4–17	9–36

Note: Tax Revenue impact includes sales, personal income, property, and corporation net income taxes.

Biomass Fuels Impact

In addition to operating biomass power plants, West Virginia could also manufacture biomass fuels. Estimates provided to the BBER indicate that biomass fuels could generate between $99 million and $512 million in annual operating expenditures in the state. As before, we have represented this spending as a single biomass fuels manufacturing facility located in the state of West Virginia. We estimate that a biomass fuels facility of this size would generate a total of between $135 million and $697 million in annual economic activity in the state, of which between $36 million and $185 would come in secondary supplier industries (Table J.3).

Based on national average employment, the biomass fuels plant would be expected to employ between 68 and 354 workers directly at the facility, with another 227 to 1,171 workers employed in secondary supplier industries. Workers at the manufacturing plant would be expected to earn approximately $10 to $50 million in annual labor income, with an additional $10 million and $52 million paid to workers in secondary industries.

The plant would be expected to generate between $1 million and $5 million in state and local tax revenue annually, with another $1 million to $5 million coming in secondary impacts, for a total tax revenue impact of between $2 million and $10 million.

Table J.3. Annual Economic Impact of Biomass Fuels Spending

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	99–512	36–185	135–697
Employment (jobs)	68–354	227–1,171	295–1,525
Labor Income ($, millions)	10–50	10–52	20–102
Total Taxes ($, millions)	1–5	1–5	2–10

Note: Tax Revenue impact includes sales, personal income, property, and corporation net income taxes.

Direct Air Capture Impact

Finally, West Virginia could sequester carbon directly from the air using direct air capture (DAC). This technology is in its infancy, so there is little data on the economic potential of this industry in the state. Because this technology is not currently in use on a large scale, we have modeled the potential economic impact of DAC as if it were similar to the industrial gas manufacturing industry, which we believe would most closely match the supply chain for DAC. Because we are unclear as to the scope of individual manufacturing facilities, we have represented this spending over the entire DAC industry located in the state of West Virginia.

Estimates provided to the BBER indicate a wide range of potential economic impacts, from zero dollars to more than $1.6 billion annually. Obviously, if the industry does not locate in West Virginia, there would be no economic impact; thus, the impacts given here are for the maximum possible expenditure in this range.

Given these assumptions, we estimate that a DAC industry of this size could generate a maximum of $2.7 billion in annual economic activity in the state, of which about $1.1 billion would come in secondary supplier industries (Table J.4). Based on national average employment for industrial gas manufacturing, the DAC industry could employ up to 1,740 workers directly in the state, with another 4,662 workers employed in secondary supplier industries, for a total potential employment impact of more than 6,400 workers. Workers in the industry would be expected to earn a maximum of $254 million in annual labor income, with another $269 million paid to workers in secondary industries. The industry would be expected to generate a maximum of $27 million in state and local tax revenue annually, with another $29 million coming in secondary impacts, for a total tax revenue impact of $56 million.

Table J.4. Annual Economic Impact of Direct Air Capture Spending

	Direct Impact	Indirect & Induced Impact	Total Economic Impact
Output ($, millions)	0–1,608	0–1,055	0–2,663
Employment (jobs)	0–1,740	0–4,662	0–6,402
Labor Income ($, millions)	0–254	0–269	0–523
Total Taxes ($, millions)	0–27	0–29	0–56

Note: Tax Revenue impact includes sales, personal income, property, and corporation net income taxes.