TrapRock

Enabling Geologic Carbon Sequestration on Washington State's Trust Lands to Meet Its Climate and Clean Energy Commitments

Carbon Containment Lab

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About the Carbon Containment Lab

The Carbon Containment Lab is a public charity advancing research and education for a public benefit. The Carbon Containment Lab applies scientific, entrepreneurial, and investment expertise, creating an enabling environment for emergent climate solutions.

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Acronyms

AEM: airborne electromagnetic (survey)

AFY: acre-feet per year

AOI: area of interest

ASR: aquifer storage and recovery

BDMT: bone-dry metric ton

BECCS: bioenergy with carbon capture and storage

BiCRS: biomass carbon removal and storage

BGS: below ground surface

BPA: Bonneville Power Administration

CCA: Climate Commitment Act

CCAP: Comprehensive Climate Action Plan

CCS: carbon capture with sequestration

CDR+S: carbon dioxide removal with sequestration

CETA: Clean Energy Transformation Act

CETI: Clean Energy Transition Institute

CFS: Clean Fuel Standard

CO_2: carbon dioxide

CO_2e: carbon dioxide equivalent

Commerce: Washington State Department of Commerce

CRBG: Columbia River Basalt Group

DAC: direct air capture

DACCS: direct air carbon capture and storage

DAHP: Washington State Department of Archaeology and Historic Preservation

DNR: Washington State Department of Natural Resources

Ecology: Washington State Department of Ecology

EFSEC: Washington State Energy Facility Site Evaluation Council

EITE: emissions-intensive, trade-exposed

E-NGPP utilities: electric utilities operating natural gas power plants

EOR: enhanced oil recovery

ESWG: Ecosystem Services Work Group

GCS: geologic carbon sequestration

GHG: greenhouse gas

GNZ: Geological Net Zero

GPD: gallons per day

GPM: gallons per minute

GW: gigawatts

IPCC: Intergovernmental Panel on Climate Change

IRP: Integrated Resource Plan

MCL: maximum contaminant level

mD: millidarcy

MT: metric tons

MW: megawatts

MWh: megawatt-hour

NHPA: National Historic Preservation Act

P3: public-private partnership

PHMSA: Pipeline and Hazardous Materials Safety Administration

PNNL: Pacific Northwest National Laboratory

PTRCI: Properties of Traditional Religious and Cultural Importance

RCRA: Resource Conservation and Recovery Act

RCW: Revised Code of Washington

SEPA: State Environmental Policy Act

SWDA: Safe Drinking Water Act

TCP: Traditional Cultural Places

TDS: total dissolved solids

UIC: Underground Injection Control

USDOE: U.S. Department of Energy

USDW: underground source of drinking water

USEPA: U.S. Environmental Protection Agency

USFS: U.S. Forest Service

USGS: U.S. Geological Survey

UTC: Washington Utilities and Transportation Commission

WAC: Washington Administrative Code

WAG: water-alternating-gas

WGS: Washington Geological Survey

WISAARD: Washington Information System for Architectural and Archaeological Records Data

Executive Summary

Washington State faces a dual imperative: meeting its ambitious climate commitments while continuing to provide affordable, clean, and firm energy to its residents. Succeeding on both fronts will require utilizing carbon capture and removal and forming groundbreaking partnerships to transform the State into a hub for geologic carbon sequestration.

Washington is underlain by basalt formations capable of storing carbon dioxide for millennia. The Columbia River Basalt Group, in particular, has great potential to store approximately 40 billion metric tons of carbon dioxide. Meanwhile, up to 38.7 million metric tons of carbon dioxide captured in the State could have need for this storage solution annually, including 19.9 million metric tons if forests at risk of wildfire are thinned and if this biomass is utilized at new or existing bioenergy facilities. Growth of the direct air capture industry would increase this volume of carbon dioxide potentially needing permanent containment.

The Washington State Department of Natural Resources can and should foster this critical climate solution. But, the agency alone cannot ensure development of an entire carbon dioxide storage ecosystem at the speed and scale necessary to combat the climate crisis. A public-private partnership is best suited to rise to this challenge.

The Department of Natural Resources and key public and private partners should collaborate to enable geologic carbon sequestration on select state trust lands. A nonprofit Executive Secretariat should provide administrative, policy, and outreach and engagement support, beginning with preparation of a statewide siting strategy informed by government-to-government consultation with Indian Tribes. Geophysical research sponsored by the Carbon Containment Lab indicates that initial surveying of potential sites can occur with no ground disturbance.

A preliminary analysis indicates that three regions within the Columbia River Basalt Group are best suited for safe and permanent geologic carbon sequestration: Canoe Ridge/Horse Heaven Hills, Palouse Slope, and Rattlesnake Hills. 339 parcels of state trust lands, representing 127,588 acres, are situated within these three areas of interest. Should the Department of Natural Resources make these state trust lands available for lease for geologic carbon sequestration, and if five to ten sites become operational at average commercial scale, over a 75-year lease period, the agency could produce an additional $3.8 million to $6.5 million for the public education system and other trust beneficiaries.

With the agency's leadership and legislative backing, a coordinated effort among government, nonprofit, academic, and industry partners could, within three years, strengthen the State's position to meet its net-zero commitment, reduce wildfire risk, create new jobs, and generate a new revenue stream for public education.

I. Background

1. Introduction
2. Climate Goals and Clean Energy Needs
3. Injection Techniques and Mineralization Science
4. Project Development Hurdles

Figure 1. Photo of basalt formation, WA. *Carbon Containment Lab.*

1. Introduction

Introduction

State leadership is critical for reducing greenhouse gas (GHG) emissions and advancing innovative and effective solutions needed to address the climate crisis. Chief among these is the safe and permanent sequestration of carbon dioxide (CO_2). **Washington State is uniquely positioned to serve the interests of its residents and the world by serving as a global hub for geologic carbon sequestration (GCS).**

The Intergovernmental Panel on Climate Change (IPCC) has declared carbon sequestration necessary for limiting warming to 2°C or less by 2100.[1] So has Washington.[2] Indeed, Washington's climate goals can be achieved only through a robust program of carbon capture with sequestration (CCS) and CO_2 removal with sequestration (CDR+S) operating alongside the State's emission-reduction programs. The State's commitment to reducing its GHG emissions 95% below 1990 levels with net-zero emissions by 2050 depends on sufficient deployment of CCS at hard-to-decarbonize sources to achieve carbon neutrality and CDR+S to offset residual GHG emissions and legacy carbon pollution.[3]

> It is the policy of the State "to promote the removal of excess carbon from the atmosphere through voluntary and incentive-based sequestration activities in Washington" and "to prioritize carbon sequestration in amounts necessary to achieve [our] carbon neutrality goal[.] - RCW 70A.45.100(1).

Fortunately, the State has vast basalt resources, onshore and offshore, that can permanently and safely sequester CO_2. Field tests show CO_2 injected into basalt reacts with calcium, magnesium, and iron ions to form stable carbonate minerals, mineralizing within the pore space into rock.[4] The flood basalts known as the Columbia River Basalt Group (CRBG) in

1. IPCC, *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. P.R. Shukla et al. (Cambridge, UK and New York, USA: Cambridge University Press, 2022), https://doi.org/10.1017/9781009157926.

2. Engrossed Second Substitute H.B. 2311, 66th Leg., Reg. Sess (2020) ("Based on the current science and emissions trends, … the [L]egislature finds that avoiding global warming of at least [1.5°C] is possible only if global [GHG] emissions start to decline precipitously, and as soon as possible… In addition, all pathways to [1.5°C] rely on some amount of negative emissions through carbon sequestration. It is therefore the intent of the [L]egislature to strengthen Washington's statutory [GHG] limits to reflect current science … and to encourage voluntary actions that increase carbon sequestration[.]"); Revised Code of Washington (RCW) 70A.45.100; Washington Climate Partnership, *Draft Comprehensive Climate Action Plan* (2025), 198–200, https://waclimatepartnership.org/en/ (Measure 7.5.2).

3. RCW 70A.45.020(1)(a)(iv), (c); Washington Climate Partnership, *Draft CCAP*, 107, 109; Greenhouse Gas Inventory Unit, *2025 Summary Report on the Science of Human Caused Climate Change and Recommendations for Washington State's Greenhouse Gas Emission Reduction Limits*, (Olympia, Washington: Washington Department of Ecology, 2025), 30, https://apps.ecology.wa.gov/publications/documents/2514064.pdf.

4. Victor E. Camp et al., *Field-Trip Guide to the Vents, Dikes, Stratigraphy, and Structure of the Columbia River Basalt Group, Eastern Oregon and Southeastern Washington*, Scientific Investigations Report 2017-5022-N (Reston, VA: U.S. Department of the Interior and U.S. Geological Survey, 2017), https://doi.org/10.3133/sir20175022N; Sandra Ó Snæbjörnsdóttir et al., "Carbon Dioxide Storage through Mineral Carbonation," *Nature Reviews Earth & Environment* 1, no. 2 (2020): 90–102, https://doi.org/10.1038/s43017-019-0011-8; B. Peter McGrail et al., "Injection and Monitoring at the Wallula Basalt Pilot Project," *Energy Procedia*, 12th International Conference on Greenhouse Gas Control Technologies, GHGT-12, 63 (January 2014): 2939–48, https://doi.org/10.1016/j.egypro.2014.11.316.

particular have great potential to sequester and lock away 40 billion metric tons (MT) of CO_2 for millennia—substantially more CO_2 than the entire United States needs to draw down from the atmosphere and sequester to reach net-zero emissions by mid-century.[5]

This being the case, Washington could become a global leader in an industry of the future that offers environmental and economic benefits. In addition to meeting state climate and clean energy goals, GCS projects will employ skilled workers. The State also could accrue revenue from GCS project developers needing to lease land and purchase pore space rights.

However, without substantial political, financial, and policy support, the State's potential to serve as a GCS hub will remain unrealized. GCS projects in Washington face logistical and economic hurdles compared to GCS projects in states with oil and gas infrastructure.[6] For example, work remains to characterize the State's subsurface basalt reservoirs, and the State has not yet established a regulatory framework for GCS. Private capital is thus disincentivized to invest in-state, despite the fact that sequestration in basalt offers a superior containment mechanism—through mineralization—to conventional GCS, which injects into depleted petroleum reservoirs or deep saline aquifers.[7]

Realizing Washington's opportunity for grand-scale GCS requires proactive State leadership and robust partnerships with public and private entities that, in combination, will bring the requisite technical expertise, financial resources, legal authority, and drive to make GCS a near-term reality.[8] This paper proposes a public-private partnership (P3) model to incentivize, site, and monitor GCS projects on state trust lands managed by the Washington Department of Natural Resources (DNR). A P3 would efficiently de-risk GCS siting, catalyze progress to net zero, and ensure just and environmentally responsible deployment while unlocking new sources of revenue for funding the public school system.

This comprehensive report is divided into three parts: background, siting assessment, and P3 planning. First, we describe Washington's need for GCS from a climate and clean energy perspective, the current techniques for injecting and storing CO_2 underground, and the project development hurdles inhibiting deployment of these GCS techniques in the State. Second, we assess, at a desktop-level of review, Washington's CO_2 sources, geology, hydrogeology, and known cultural resources to determine which state trust lands within the CRBG could best host and be prioritized for potential GCS projects. Third, we conclude by proposing a governance structure and funding model for a P3 that would establish GCS as a key component of Washington's climate, clean energy, and economic competitiveness strategies.

5. *See generally* Ruoshi Cao et al., "Gigaton Commercial-Scale Carbon Storage and Mineralization Potential in Stacked Columbia River Basalt Reservoirs," *International Journal of Greenhouse Gas Control* 137, no. 104206 (September 2024), https://doi.org/10.1016/j.ijggc.2024.104206; A.R. Crimmins et al., *Fifth National Climate Assessment* (2023), 32–24, https://repository.library.noaa.gov/view/noaa/61592/noaa_61592_DS1.pdf?download-document-submit=Download.

6. Washington Climate Partnership, *Draft CCAP*, 107, 109, 197–98.

7. McGrail et all., "Injection and Monitoring at the Wallula Basalt Pilot Project," 2939–48.

8. *See, e.g.*, EA Engineering, Science, and Technology, Inc., PBC, *Carbon Dioxide Removal Evaluation Study,* Publication 25-14-066 (Olympia, Washington: Washington State Department of Ecology, September 2025), 98–99, https://apps.ecology.wa.gov/publications/SummaryPages/2514066.html.

2. Climate Goals and Clean Energy Needs

Climate Goals and Clean Energy Needs

The impacts of the climate crisis, fueled by increasing GHG concentrations in the atmosphere, are well-documented in Washington. Anthropogenic climate change is increasingly evident in the State through a range of biophysical impacts, including forest fires, drought, sea level rise, ocean acidification, decreased snowpack, and other changes to water supply and quality.[9] These biophysical impacts have economic repercussions, including increasing risks to property and communities from wildfire, as well as for the agricultural sector and hydropower production due to increasingly severe and frequent drought episodes.[10] Climate change also threatens the health and wellbeing of Washingtonians. For example, in 2021 alone, more than 400 people died from direct and indirect heat-related causes during a week-long extreme heat event.[11]

To fight these and other adverse impacts of the climate crisis, Washington set one of the most ambitious climate targets in the nation: delivering net-zero emissions by mid-century.[12] The challenge of achieving this commitment across all sectors of society is significant, and so Washington has enacted laws and policies designed to meet its climate target.

Decarbonization Obligations

The Climate Commitment Act (CCA), Clean Energy Transformation Act (CETA), and Clean Fuel Standard (CFS) are three core laws governing the State's transition away from fossil fuels and towards net-zero emissions. The CCA requires the State's largest emitters to progressively reduce their GHG emissions.[13] CETA requires energy providers to increase the statewide supply of clean energy, and the CFS requires fuel providers to lower the carbon intensity of transportation fuels. [14]

Climate Commitment Act

Washington has set 2030 and 2040 interim emissions-reductions commitments, or "caps," to ensure Washington meets its 2050 net-zero target. (See Figure 2.) By 2030, overall GHG emissions must be reduced to 50 million MT of carbon dioxide equivalent (CO_2e) (45% below 1990 levels); by 2040, to 27 million MT CO_2e (70% below 1990 levels); and, by 2050, to 5 million MT CO_2e (95% below 1990 levels).[15] By 2050, the State must use CDR+S to draw down legacy carbon pollution from the atmosphere to compensate for residual emissions.[16]

9. Greenhouse Gas Inventory Unit, *2025 Summary Report on the Science of Human Caused Climate Change*, 30–31.

10. See C. L. Raymond et al., *Biophysical Climate Risks and Economic Impacts for Washington State*, ed. Climate Impacts Group (Seattle: University of Washington, December 2022), 15–30, https://cig.uw.edu/wp-content/uploads/sites/2/2023/01/Biophysical-Climate-Risks-and-Economic-Impacts-for-Washington-State_UW_Climate_Impacts_Group_Dec2022.pdf.

11. J. Vogel et al., *In the Hot Seat: Saving Lives from Extreme Heat in Washington State*, ed. Climate Impacts Group (Seattle: University of Washington, 2023), 1, https://cig.uw.edu/wp-content/uploads/sites/2/2023/06/CIG-Report-Heat-202-pages.pdf.

12. RCW 70A.45.020(1)(a),(c).

13. RCW 70A.65.080.

14. RCW 19.405.040; RCW 70A.535.025.

15. RCW 70A.45.020(1)(a).

16. *Id.* at (1)(c); Washington Climate Partnership, *Draft CCAP*, 32.

CCS could serve to prevent certain GHG emissions from reaching the atmosphere at various stages throughout this decarbonization schedule.

The CCA is a cap-and-invest framework that limits economy-wide emissions through market-based regulation of the State's largest carbon emitters. Covered entities—businesses responsible for annual emissions exceeding 25,000 MT CO_2e—are required to obtain compliance instruments equivalent to 100% of their annual emissions over four-year compliance periods.[17] These compliance instruments come in two forms, both of which correspond to 1 MT CO_2e: allowances and offsets. The majority of a covered entity's obligations must be met with allowances, which can be purchased through a state-run auction or through the secondary market.[18] The total number of allowances available for a given year is set by the Washington State Department of Ecology (Ecology) and is reduced over time, leading to a corresponding reduction in covered entities' collective emissions.[19] The CCA also permits covered emitters to satisfy a small portion of their obligation with offset credits, which can be obtained in exchange for investing in offset projects.[20]

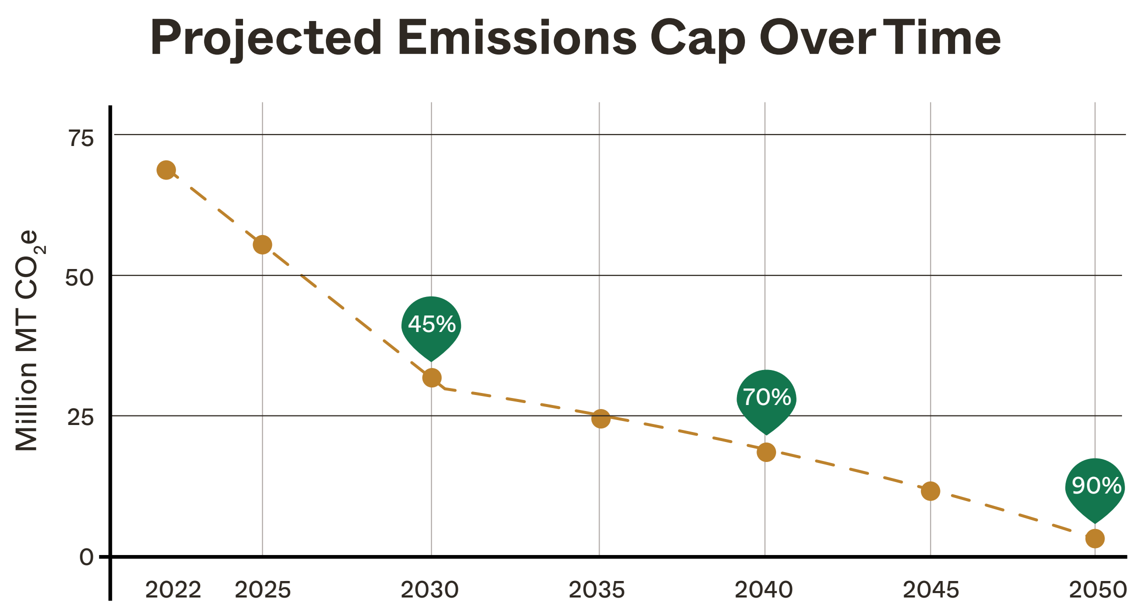

Figure 2. Washington's cap-and-invest program caps overall CO_2e emissions in the State in accordance with its 2030, 2040, and 2050 emissions-reduction commitments. Covered entities must obtain compliance instruments equivalent to their total annual emissions over four-year compliance periods.[21]

17. RCW 70A.65.080.

18. RCW 70A.65.170(3).

19. RCW 70A.65.070(2).

20. WAC 173-446-020. Allowances cost $64.30 at the September 2025 auction, and offset credits, which are purchased directly from project developers or other market participants, can be cheaper. "Why Washington Climbed to the Top of the Nation's Gas Price Charts," *Future 42*, September 19, 2025, https://future42.org/why-washington-climbed-to-the-top-of-the-nations-gas-price-charts.

21. Adapted from "Washington's Cap-and-Invest Program," Washington State Department of Ecology, accessed November 21, 2025, https://ecology.wa.gov/air-climate/climate-commitment-act/cap-and-invest.

Electric utilities, natural gas utilities, and emissions-intensive, trade-exposed (EITE) industries receive no-cost allowances.[22] Electric utilities subject to CETA, including those operating natural gas power plants (E-NGPP utilities), receive no-cost allowances to help mitigate the cost burden of decarbonization and to prevent associated increases in the cost of electricity passed on to consumers.[23] The volume of no-cost allowances issued to electric utilities is updated annually and incorporates projections of the electricity resource mix that will allow electric utilities to serve the electric retail load.[24]

Approximately 40 facilities qualify as EITEs, including petroleum refineries, pulp and paper facilities, and facilities producing cement, chemicals, and metals.[25] These hard-to-decarbonize industrial sources are given no-cost allowances, again in decreasing amounts, so they are able to decarbonize while remaining in state and competitive globally.[26] The Legislature has not yet determined whether and, if so, how many, no-cost allowances EITEs will receive between 2035 and 2050, so the number could decrease precipitously or slowly.

In general, as the number of no-cost allowances available to electric utilities and EITEs decreases, these companies will need to compete to purchase allowances at auction at increasingly higher prices, considering that as supply decreases, demand will drive up cost. The cost of compliance for fossil-based power producers and hard-to-decarbonize industrial sources will consequently increase, incentivizing investment in energy-efficiency gains and CCS technologies.[27]

Offset credits currently can be generated from four types of projects: U.S. forest projects; urban forestry projects; ozone depleting substances projects; and livestock projects, such as methane capture.[28] The State has not yet developed a protocol for CDR+S or CCS, though both will need to be implemented in order to meet the State's 2050 net-zero commitment.

Clean Energy Transformation Act

CETA is a command-and-control regulatory framework that aims to reduce emissions from Washington's electric utility sector. It compels electric utilities to decrease the supply

22. RCW 70A.65.110–.130.

23. WAC 173-446-230(1), (2).

24. *Id*. at (2)(b), (2)(j).

25. RCW 70A.65.110.

26. WAC 173-446-220(2)(a); *see also* "Emissions-Intensive, Trade-Exposed Industries (EITEs)," Ecology, accessed October 25, 2025, https://ecology.wa.gov/air-climate/climate-commitment-act/cap-and-invest/emissions-intensive-trade-exposed-industries.

27. "Latest Carbon Auction Raises $446M as WA Experiences Highest Gas Prices in Nation," *The Center Square*, September 15, 2025, https://www.thecentersquare.com/washington/article_dd578cc3-f08b-4052-aea3-a1168d046adc.html; *see also* Tim Clouser, "CCA Compliance Could Cost Spokane over $210M to Renovate Waste-to-Energy Plant," *The Center Square*, September 15, 2025, https://www.thecentersquare.com/washington/article_ac79345c-bf93-476e-9a44-915968688bb8.html.

28. WAC 173-446-500, -505.

of fossil fuel-derived energy and increase the supply of clean energy. CETA establishes three decarbonization milestones for covered electric utilities:

1. No coal by 2026: By December 31, 2025, electric utilities must no longer use coal-fired generation to serve load in Washington;[29]

2. 100% carbon-neutral by 2030: All retail sales of electricity to Washington customers must be carbon-neutral by January 1, 2030;[30] and

3. Carbon-free by 2045: All retail sales of electricity to Washington customers must be supplied by sources of nonemitting electric generation (e.g., nuclear) and/or renewable resources (e.g., wind, solar, geothermal) by January 1, 2045.[31]

An electric utility can achieve carbon neutrality by using a combination of nonemitting electric generation, electricity from renewable resources, and alternative compliance options like investing in "energy transformation projects" that do not result in a net increase in fossil fuel use.[32] Between 2030 and 2045, emitting power sources cannot represent more than 20% of an electric utility's overall fuel mix.[33]

There are caveats to CETA's mandates. An energy utility may be temporarily relieved of its obligation to meet CETA's standards if doing so would conflict with its ability to provide reliable and adequate electricity.[34] It may also adopt a slower transition to avoid "rate shock."[35]

Clean Fuel Standard

The CFS requires fuel suppliers to reduce the carbon intensity of transportation fuels to 45% below 2017 levels by 2038.[36] Two options for fuel suppliers to achieve these reductions are purchasing credits generated by those selling fuels with carbon intensities below the cap or blending with biofuels.[37] Although the CFS explicitly allows for the generation of credits from CDR+S and CCS associated with transportation, the State currently does not have such a protocol.[38]

29. RCW 19.405.030(1)(a).

30. *Id*. at .040(1).

31. *Id*. at .050(1).

32. *Id*. at .040(b) (listing "alternative compliance options"). "'Energy transformation project' means a project or program that: [p]rovides energy-related goods or services, other than the generation of electricity; results in a reduction of fossil fuel consumption and in a reduction of the emission of greenhouse gases attributable to that consumption; and provides benefits to the customers of an electric utility." RCW 19.405.020(18)(a).

33. *Id*. at .040(1)(b).

34. *Id*. at .090(3), (5).

35. *Id*. at .060(1)–(2); *see also* "Clean Energy Transformation Act," Washington State Department of Commerce, last modified on August 5, 2025, https://www.commerce.wa.gov/energy-policy/electricity-policy.

36. RCW 70A.535.025(5).

37. *See generally* WAC 173–424.

38. RCW 70A.535.050 (allowing the generation of credits from activities that support the reduction of GHG emissions associated with transportation, including CCS and direct air capture with storage). California has adopted a protocol under its Low Carbon Fuel Standard crediting CCS projects that sequester CO_2 onshore in saline reservoirs or depleted oil and gas reservoirs that could serve as a template for in-state GCS in basalt.

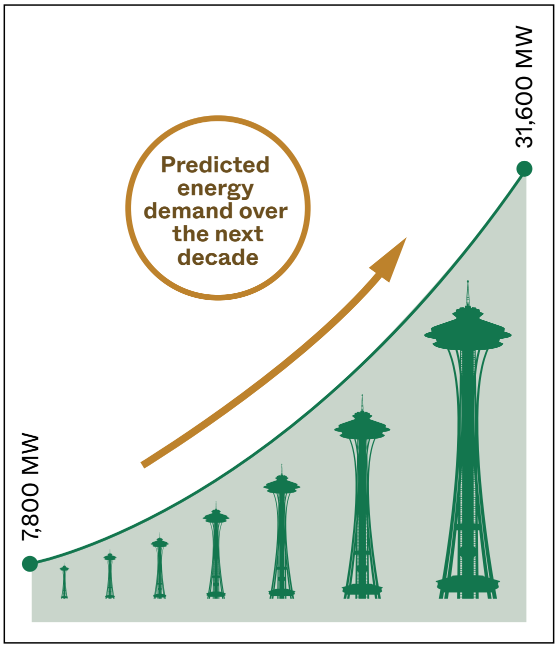

Figure 3. Representation of the Pacific Northwest Utilities Conference Committee's prediction that, by 2035, energy demand will increase to 31,600 average MW, equivalent to adding seven Seattle-sized cities to the power grid.[42]

Constraints Inhibiting Washington's Clean Energy Transition

The ability of electric utilities to comply with the CCA and CETA and satisfy state climate goals depends on the availability of clean energy. The future development of clean energy faces increasing challenges, however, including supply constraints amid surging demand in addition to infrastructure, political, and regulatory obstacles.

First, electricity demand is outpacing the capacity of the existing grid. Demand-side pressures, stemming from rapid construction of data centers, population growth, and increasing electrification of transportation and heating, are mounting.[39] Several organizations (e.g., research, nonprofit, and an interstate compact agency) predict that energy demand will grow exponentially. The Clean Energy Transition Institute (CETI) predicts electricity demand in Washington will grow 70 to 92% beyond 2020 levels by 2050.[40] **The Pacific Northwest Utilities Conference Committee predicts that within one decade energy demand will increase by 7,800 average megawatts (MW) to 31,600 average MW—an increase equivalent to adding seven Seattle-sized cities to the power grid.[41] (See Figure 3.)**

39. *See, e.g.*, "Washington Data Centers & Colocation," Baxtel, accessed September 27, 2025, https://baxtel.com/data-center/washington (Home to 116 data centers and counting, Washington now ranks among the nation's top 10 data center markets, which adds significant strain on an already struggling power grid.); *see also* Lulu Ramadan and Sydney Brownstone, "How a Washington Tax Break for Data Centers Snowballed Into One of the State's Biggest Corporate Giveaways," *ProPublica*, August 4, 2024, https://www.propublica.org/article/washington-data-centers-tech-jobs-tax-break.

40. CETI, *Washington State Energy Strategy Technical Consulting* (September 2020), 52, https://www.commerce.wa.gov/wp-content/upe loads/2020/09/2020-09-15-AC-Meeting-CETI-Team-Presentation-Deck-Final.pdf; see also Interagency Clean Energy Siting Coordinating Council, *Annual Report: Improving Clean Energy Project Siting and Permitting* (October 2025), 5, https://apps.ecology.wa.gov/publications/SummaryPagl es/2506011.html. (Recent analysis indicates the 2021 State Energy Strategy, which projects Washington's electricity needs for achieving state GHG emissions reductions and clean energy requirements, underestimates the amount of electricity required to power the State given growing demand.) The Northwest Power and Conservation Council predicts electricity demand in its four-state region could double in 20 years. See Northwest Power and Conservation Council, *9th Power Plan Demand Forecast* (April 2025), 38, https://www.nwcouncil.org/fs/19380/2025_0429_2.pdf.

41. *See* Pacific Northwest Utilities Conference Committee, Northwest Regional Forecast of Power Loads and Resources (April 2025), 5, https://www.pnucc.org/wp-content/uploads/2025-PNUCC-Northwest-Regional-Forecast-final.pdf; Tony Schick and Monica Samayoa, "How the Pacific Northwest's Dream of Green Energy Fell Apart," *KUOW*, May 12, 2025, https://www.kuow.org/stories/how-the-pacific-northwest-s-dream-of-green-energy-fell-apart.

42. Pacific Northwest Utilities Conference Committee, Northwest Regional Forecast of Power Loads and Resources, 5.

Meanwhile, extreme weather events and drought, fueled by climate change, are adding supply-side pressures to the grid.[43] For example, hydropower production, which accounts for almost half of the State's electric utilities fuel mix, dropped by approximately 10% over the last 20 years primarily due to reduced precipitation stored in snowpack.[44]

It is noteworthy that as demand for electricity has increased, reliance on fossil-derived power has increased.[45] (See Figure 4.) These trends have placed Washington off track from reaching its interim clean energy and climate targets. In fact, Washington's 2021 GHG emissions were 2.3% higher than the target established by state law, despite the temporary emission reductions caused by the COVID-19 pandemic in 2020.[46]

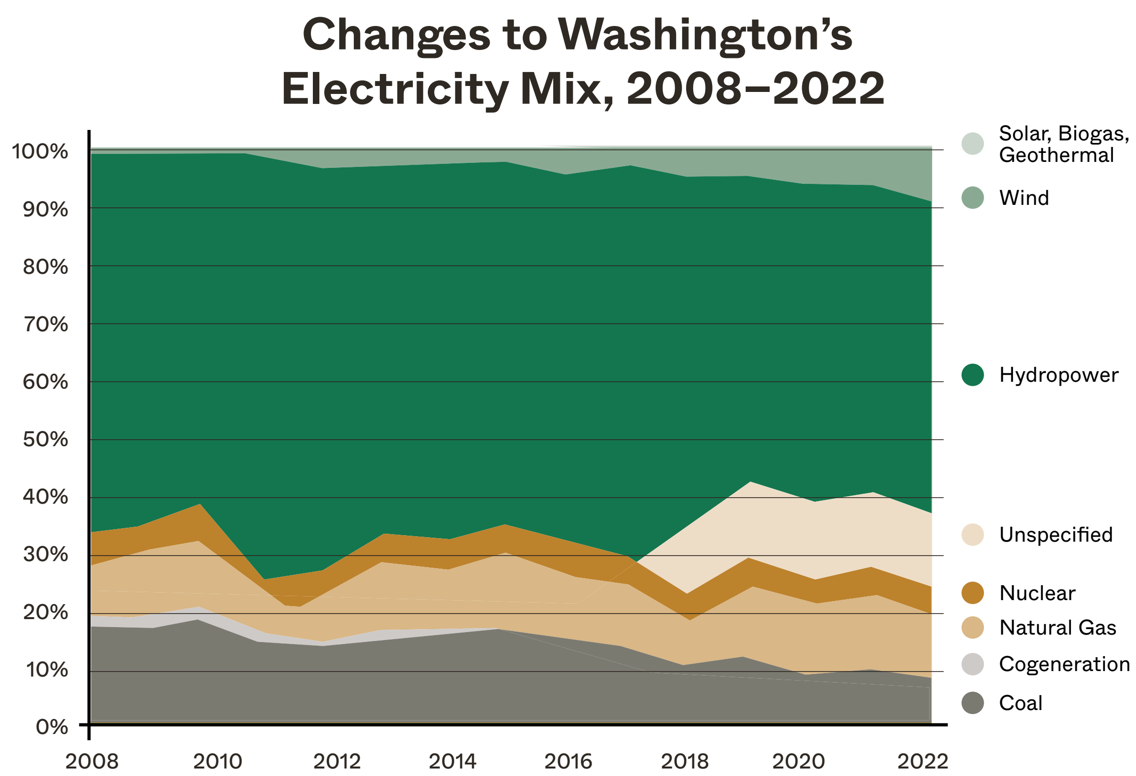

Figure 4. As electricity demand continues to rise and hydropower production declines, Washington's energy mix is becoming increasingly carbon-intensive. To meet growing demand, the State has relied more heavily on natural gas and "unspecified" power—electricity purchased on the open market that most likely originates from carbon-emitting sources. Counties with large data center markets have shown the highest dependence on this unspecified fuel.[47]

43. The Greater Northwest faces a supply deficit of around 1,300 MW in 2026, which is projected to grow to 8,700 MW by 2030. New resource additions have been slow to come online and are located primarily outside of Washington. Arne Olson et al., *Resource Adequacy and the Energy Transition in the Pacific Northwest: Phase 1 Results*, ed. Energy and Environmental Economics (Washington Utilities and Transportation Commission Washington Department of Commerce, September 2025), 9, https://www.utc.wa.gov/sites/default/files/2025-10/Revised%20V3%20E3%20Presentation%20RA%20Study%20September%2022%20WA%20RA%20Meeting.pdf.

44. Greenhouse Gas Inventory Unit, *Washington State Greenhouse Gas Emissions Inventory: 1990–2021*, (Olympia: Ecology, January 2025), 28, https://apps.ecology.wa.gov/publications/documents/2414077.pdf.

45. Lulu Ramadan and Sydney Brownstone, "Data Centers Guzzle Power, Threatening WA's Clean Energy Push," *The Seattle Times*, July 28, 2024, https://www.seattletimes.com/seattle-news/times-watchdog/power-hungry-how-the-data-center-boom-drained-wa-of-hydropower.

46. Greenhouse Gas Inventory Unit, *Washington GHG Inventory*, 8.

47. Adapted from Ramadan and Brownstone, "Data Centers Guzzle Power, Threatening WA's Clean Energy Push."

Second, substantial infrastructure improvements to the grid are needed to increase the supply of clean energy available. This challenge has proven to be one of the greatest bottlenecks in Washington's renewable energy transition.[48] The Bonneville Power Administration (BPA) owns and operates most of the State's transmission lines under a bureaucratic federal structure with no state or local representation.[49] Interconnection to BPA transmission lines often has multi-year delays.[50] Since 2015, 469 large renewable projects have applied to connect to BPA's grid across Washington and Oregon, yet only one has won BPA's approval.[51]

Third, the development of new renewable energy projects faces significant political challenges. The rapid phaseout of federal grants and tax credits for renewable energy, electric vehicles, and grid infrastructure could substantially slow clean energy deployment and grid enhancement in Washington.[52] In addition, growing community opposition to certain types of clean energy projects, such as hydropower and large wind turbines, complicates renewable energy development in the State.[53]

Fourth, delays for siting and permitting new projects compound these other obstacles and makes Washington less attractive to clean energy project developers.[54] Permitting of clean energy projects in Washington is often too slow, unpredictable, and costly because of a "lack of specific timelines for completing permitting, lack of clarity about mitigation and other requirements ..., and uncertainty about how many studies and surveys will be required[.]"[55] For example, Puget Sound Energy's Energize Eastside transmission project, which involved upgrading a single substation and approximately 16 miles of transmission lines, took 12 years to receive all necessary permits.[56] And permitting for the Horse Heaven Hills project, a combined solar-wind-battery storage project designed to be Washington's largest source of carbon-free power, took eight years from the time environmental surveys began until receiving the Governor's approval; the project is currently stalled under litigation.[57] Recent state legislation to reform siting and permitting of clean energy projects to expedite deployment has failed.[58] Plus, due to national build-rate constraints, most new renewable energy capacity in Washington is expected not to be added until after 2035.[59]

48. Interagency Clean Energy Siting Coordinating Council, *Annual Report*, 11.

49. Tony Schick and Monica Samayoa, "Liberal Oregon and Washington Vowed to Pioneer Green Energy. Almost Every Other State Is Beating Them.," *ProPublica*, May 12, 2025, https://www.propublica.org/article/oregon-washington-green-energy-bonneville.

50. Interagency Clean Energy Siting Coordinating Council, *Annual Report*, 11.

51. Schick and Samayoa, "Liberal Oregon and Washington Vowed to Pioneer Green Energy."

52. Federal tax credits served as a critical catalyst for many wind and solar projects in states pursuing ambitious renewable energy goals, including Washington. *See* Alex Brown, "States Scramble to Complete Renewable Energy Projects before Tax Credits Expire," *Stateline*, August 5, 2025, https://stateline.org/2025/08/05/states-scramble-to-complete-renewable-energy-projects-before-tax-credits-expire.

53. *See, e.g.*, James Conca, "Washington State's Approaching Energy Crisis – Good Intentions Gone Wrong?," *Forbes*, June 15, 2021, https://www.forbes.com/sites/jamesconca/2021/06/15/washington-states-approaching-energy-crisis--good-intentions-gone-wrong.

54. *See* Beveridge and Diamond, *Siting and Permitting Reform in Washington: A Report to the Washington Department of Commerce under RCW 43.394.020(3)(a)*, 6, https://www.bdlaw.com/content/uploads/2024/07/2024-07-23-Commerce-Reports-Permitting-Report-Final.pdf (referencing Conrad Swanson, "How An Endangered Hawk Could Topple Plans for Washington's Largest Wind Farm," *The Seattle Times*, February 21, 2024, and explaining that "[I]t's just too risky to invest in Washington.").

55. *Id*. at 1–2.

56. *Id*. at 34.

57. *Id*. at 23; "Horse Heaven Wind Project," Washington State Energy Facility Site Evaluation Council, accessed October 25, 2025, https://efsec.wa.gov/facilities/horse-heaven-wind-project.

58. *See, e.g.*, HB 1237, 69th Leg., Reg. Sess. (2025) (Had this bill passed, it would have facilitated predictable and timely application decisions by Washington State Energy Facility Site Evaluation Council); HB 1328, 69th Leg., Reg. Sess. (2025) (Had this bill passed, it would have accelerated development of clean energy projects and transmission lines by creating a Clean Energy Development Office within Commerce).

59. Evolved Energy Research, *Net-Zero Northwest Technical Report*, June 2023, accessed September 27, 2025, 219, https://cdn.prod.website-files.com/64512dc345012a0e621f373f/655bd194fe78e74eabe87281_Evolved_NZNW_Energy_Technical%20Report_06-2023.pdf.

The Western Electricity Coordinating Council predicts that if the region's current energy trends continue, residents will face consistently rising energy bills and almost a month of brownout or blackout risk annually.[60] Washington, which once enjoyed one of the lowest costs of electricity in the country, is now experiencing a rapid price surge.[61] The average retail price for residential electricity climbed 13% between May 2024 and May 2025, in contrast to a 7% price increase nationally.[62] During a winter storm in 2024, electricity prices rose to more than $1,000 per megawatt-hour (MWh), 18 times the usual price.[63] The situation is so urgent that U.S. Senators Cantwell and Murray signed a letter urging greater Western grid cooperation and the creation of a broader regional power market.[64] A belief that the State's decarbonization commitments have caused these spikes in utility prices is causing rising public animus against those laws.[65]

The Role of CCS and CDR+S

Clean Firm Energy

Slow deployment of clean energy projects causes Washington to increasingly face an impossible choice: temporarily suspend its clean energy mandates or risk rolling blackouts, rising prices, and public ire. But, there is another way to protect and sustain CETA—to provide clean energy without compromising public support for decarbonization: retrofitting existing natural gas power plants far from end-of-life with CCS and maintaining them temporarily, until renewable capacity satisfies demand and supports a carbon-free grid.

The State requires reliable electricity now more than ever, not only for everyday demand but also to support the buildout of renewable infrastructure required to reach its decarbonization goals—particularly the energy-intensive production of cement and steel needed to manufacture and install solar panels and transmission lines. To satisfy this growing need for energy, the State's grid is becoming increasingly dependent on natural gas to meet both baseload and peak demand.[66] In 2023, the four E-NGPP utilities reported fuel mixes containing natural gas in the following amounts: Avista (41%), Clark County PUD #1 (32%),

60. Western Electricity Coordinating Council, "Western Assessment of Resource Adequacy 2024," 2024, https://feature.wecc.org/wara; *see also* H.B. 1117, 68th Leg., Reg. Sess (2023).

61. Conca, "Washington State's Approaching Energy Crisis – Good Intentions Gone Wrong?"

62. Melissa Santos, "Power Prices and Demand Are Rising in Washington State," *Axios*, August 12, 2025, https://www.axios.com/local/seattle/2025/08/12/washington-utility-bill-increase-electric-grid-energy-demand.

63. Tony Schick and Monica Samayoa, "Higher Prices, Rolling Blackouts: The Northwest Is Bracing for the Effects of a Lagging Green Energy Push," *ProPublica*, May 13, 2025, https://www.propublica.org/article/oregon-washington-green-energy-consequences.

64. Henrik Nilsson, "West Coast Senators Urge Passage of Calif. Pathways Bill," *RTO Insider*, September 8, 2025, www.rtoinsider.com/114302-senators-weigh-in-on-sb-540.

65. *See* "Latest Carbon Auction Raises $446M as WA Experiences Highest Gas Prices in Nation," *The Center Square*, September 12, 2025 https://www.thecentersquare.com/washington/article_dd578cc3-f08b-4052-aea3-a1168d046adc.html; *see, e.g.*, "Climate Commitment Act Rate Adjustments for Washington Avista Natural Gas Customers," Avista Connections, accessed September 27, 2025, https://www.myavista.com/connect/articles/2024/06/climate-commitment-act-rate-adjustments-for-washington-natural-gas-customers (In March 2024, Avista started to include a CCA charge in the natural gas rate to help offset Avista's costs to comply with the cap and invest program).

66. Natural gas is currently the second-largest in-state source of electricity. Energy Information Administration, "Washington State Profile and Energy Estimates," May 15, 2025, https://www.eia.gov/state/analysis.php?sid=WA; *see* Northwest Gas Association, "The Pacific Northwest's Green Energy Ambitions: A Gridlocked Reality," NWGA, May 14, 2025, https://www.nwga.org/post/the-pacific-northwest-s-green-energy-ambitions-a-gridlocked-reality; *see also* Ramadan and Brownstone, "Data Centers Guzzle Power, Threatening WA's Clean Energy Push."

Puget Sound Energy (30%), and PacifiCorp (19%).[67] For one E-NGPP utility, the actual share of electricity generated from natural gas was more than twice the preferred level articulated in its 2023 Electric Progress Report, suggesting unanticipated or undesired reliance on natural gas to meet energy demand.[68] Furthermore, Avista, Puget Sound Energy, PacifiCorp, and the Public Generating Pool[69] (collectively, the "Joint Utilities") all claim that expanded natural gas capacity can most economically provide firm power supplementing renewable—but intermittent—resources.[70]

This increasing reliance on power from natural gas could come in tension with CETA's demands on electric utilities. Based on their current levels of reliance, E-NGPP utilities may have difficulty complying with CETA's limitation that, when an alternative compliance option is used, emitting power sources may make up no more than 20% of their fuel mixes after 2029.[71] CETA compliance will require these four E-NGPP utilities, respectively, to decrease or maintain their use of natural gas as a share of their overall fuel mix; however, if the rate of clean energy deployment remains too slow, and E-NPGG utilities temporarily cannot provide reliable and adequate electricity without natural gas; they may be relieved temporarily of their obligations under CETA, or a slower transition may be implemented to prevent rolling brownouts and rate hikes.

If the need arises, in such a case, the State could avoid these adverse consequences, temper public animus to keep a ballot initiative against CETA at bay, and continue progressing towards its clean energy and climate goals by slightly modifying CETA to incentivize E-NGPP utilities to retrofit their existing plants with carbon capture systems. According to the State's Draft Comprehensive Climate Action Plan (CCAP), CETA supports deployment of CCS, but it appears a legislative change would be required.[72] The Legislature soon may want to reconsider CETA's restriction that emitting power sources cannot represent more than 20% of an electric utility's overall fuel mix. The Legislature could, for all E-NGPP utilities actively working to deploy new sources of clean energy and with natural gas power plants far from retirement, develop a formula such that emissions captured at those plants and then permanently sequestered do not count towards the 20% limitation. (Carbon capture systems installed at natural gas power plants capture 95% of carbon emissions.)[73]

67. *See* Energy Policy Office, *Washington Electric Utility 2023 Fuel Mix Disclosure Report* (Washington State Department of Commerce, May 2025), https://deptofcommerce.app.box.com/s/l9sqx4bcfnko3omrpk4tv8n0vbzcvsdz/file/1833951047013.

68. *See, e.g.*, Puget Sound Energy, "2023 Electric Progress Report," 2023, 3.5, https://www.pse.com/-/media/PDFs/IRP/2023/electric/chapters/00_EPR23_ChapterBook_Final.pdf (Puget Sound Energy's "preferred portfolio," representing a portfolio of diverse resources that can fulfill its CETA commitments and achieve carbon neutrality by 2030 and a carbon-free electric energy supply by 2045, for 2023 consisted of 13% electricity generated from natural gas.); *see also* Energy Policy Office, *Washington Electric Utility 2023 Fuel Mix Disclosure Report*, 60, https://deptofcommerce.app.box.com/s/l9sqx4bcfnko3omrpk4tv8n0vbzcvsdz/file/1833951047013.

69. The Public Generating Pool members are Chelan Public Utility District (PUD), Clark PUD, Cowlitz PUD, Eugene Water & Electric Board, Grant PUD, Lewis PUD, Seattle City Light, Snohomish PUD, and Tacoma Public Utilities. "Members," The Public Generating Pool, accessed October 25, 2025, https://www.publicgeneratingpool.com/members.

70. Washington State Department of Commerce and Washington Utilities and Transportation Commission, "Summary of the 2024 Annual Electricity Resource Adequacy Meeting," November 2024, 14, https://www.utc.wa.gov/sites/default/files/2025-03/2024_Resource_Adequacy_Letter_and_Summary%20-%202024-11-15.pdf.

71. RCW 19.405.040(1)(b).

72. Washington Climate Partnership, *Draft CCAP*, 109.

73. *See, e.g.*, A.J. Simon et al., *Carbon Capture for Natural Gas-Fired Power Generation*, Carbon Direct, March 3, 2025, 7, https://www.carbon-direct.com/research-and-reports/carbon-capture-for-natural-gas-fired-power-generation-low-emissions-power-to-meet-rapid-growth-in-electricity-use; "Just Catch: Standardized, Modular Carbon Capture Plant," SLB Capturi, accessed October 1, 2025, https://www.capturi.slb.com/products/just-catchTM; "How It Works," ION Clean Energy, accessed October 1, 2025, https://www.ioncleanenergy.com/how-it-works.

If this change is adopted, then the Legislature should also consider setting an explicit retirement date for natural gas power plants even with CCS, as it did for coal-fired power plants, so CCS mitigates but does not facilitate prolonged fossil fuel use.

The Joint Utilities recognize natural gas retrofitted with CCS as a potentially viable pathway for providing consistent firm power in the region, though expensive.[74] Three of the four E-NGPP utilities indicate in their Integrated Resource Plans (IRPs) awareness of or interest in the potential to deploy CCS at their natural gas power plants.[75] Puget Sound Energy, for example, describes CCS as an emerging technology that could fill a perceived gap in cost-effective clean energy sources and which they are monitoring for commercial readiness.[76] Natural gas plants retrofitted with CCS could offer a critical bridge solution during the climate transition because these plants can provide firm baseload power with minimal GHG emissions before their retirement—while renewable capacity scales up to meet demand—preventing the rate hikes and rolling brownouts that could otherwise derail the State's clean energy transition and economic growth.[77]

> "In order to meet the statewide [GHG] limits in the energy sectors of the economy, more resources must be directed toward achieving decarbonization ..., while continuing to protect all customers, but especially low-income customers, vulnerable populations, highly impacted communities, and overburdened communities. The [L]egislature finds that regulatory innovation may be needed [.]"
>
> - Engrossed Substitute H.B. 1589, 68th Leg., Reg. Sess. (2024).

Industrial Sector and Residual Emissions

In addition to potentially supporting a steady but temporary supply of clean firm power, CCS is essential for decarbonizing hard-to-decarbonize industrial sources. Washington's Draft CCAP, led by the Washington Climate Partnership comprised of staff from the Washington State Department of Commerce (Commerce) and Ecology, emphasizes the role of CCS for hard-to-decarbonize industries like pulp and paper, materials production (cement, aluminum, and steel), and chemical manufacturing, for which emissions cannot be fully addressed through

74. Washington State Department of Commerce, "2024 Resource Adequacy Meeting," 14.

75. *See* Puget Sound Energy, *2023 Electric Progress Report* (2023), 2.7, https://www.pse.com/-/media/PDFs/IRP/2023/electric/chapters/00_EPR23_ChapterBook_Final.pdf; Avista Corporation, *2025 Draft Electric IRP* (October 2024), 162, https://www.myavista.com/-/media/myavista/content-documents/about-us/our-company/irp-documents/2025/2025-draft-electric-irp-complete.pdf; PacifiCorp, 2025 *Integrated Resource Plan*, (March 2025), 2–4, https://www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/energy/integrated-resource-plan/2025-irp/2025_IRP_Vol_1.pdf.

76. PSE, *2023 Electric Progress Report*, 2.7.

77. Zach Ming et al., *Resource Adequacy in the Pacific Northwest*, ed. Energy and Environmental Economics (March 2019), 75, https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf.

energy efficiency improvements, electrification, or switching to low-carbon fuels.[78] Capturing and sequestering CO_2 emissions at these facilities, once a protocol is developed, provides perhaps the only appreciable compliance pathway to net zero.

Deploying CCS between now and mid-century presents an opportunity to begin building the infrastructure and expertise that the State will need to offset residual emissions with CDR+S. CDR+S is needed to offset residual GHG emissions from non-CO_2 gases, such as methane, nitrous oxide, and HFCs, for which no feasible mitigation measures currently exist.[79] Indeed, up to 11.6 million MT CO_2 annually will need to be drawn down from the atmosphere and sequestered to account for residual emissions.[80]

The Case for GCS

Human activities, particularly fossil fuel combustion and industrial processes, have transferred vast amounts of carbon from its slow domain in the geosphere to its fast domain in the atmosphere and biosphere, leading to global warming.[81] When this carbon is captured at natural gas power plants or hard-to-decarbonize industrial sources, or removed directly from the atmosphere, it can be utilized or sequestered. For example, captured or removed CO_2 can be used directly in beverages and refrigeration, or as a feedstock for chemical reactions that produce economically valuable products and services such as green fuels (e.g., methanol and sustainable aviation fuel), building materials, plastics, and biofertilizers.[82] These usage pathways temporarily delay the release of CO_2; however, once the fuels are burned or the products reach the end of their life cycle, the embodied CO_2 is ultimately released back into the fast domain in the atmosphere.[83] Carbon utilization alone cannot offer a permanent path to achieve the State's net-zero target.

Carbon sequestration is therefore an indispensable strategy to achieve net-zero emissions. Captured or removed CO_2 can be sequestered either in biological systems, returning the carbon to its fast cycle, or geological systems, returning the carbon to its slow cycle.[84] Like utilization, carbon storage in biological systems remains inherently prone to reversal, in this case due to land-use changes, ecosystem disturbances, or climatic extremes.[85] Carbon storage in biological systems alone also cannot offer a permanent path to achieve the State's net-zero target. (See Figure 5.)

78. Washington Climate Partnership, *Draft CCAP*, 106–107.

79. Evolved Energy Research and CETI, *WCP Summer 2025 Emissions Modeling Slide Deck* (Commerce, July 2025), 25, https://deptofcommerce.app.box.com/s/2k5pkwe9hx2u3k1fqlnbwdgnimuxkeky/file/1933744691347.

80. EA Engineering, Science, and Technology, *CDR Evaluation Study*, 3

81. "The Carbon Cycle," NASA Earth Observatory, June 2011, https://earthobservatory.nasa.gov/features/CarbonCycle.

82. Jeffrey Bobeck et al., *Carbon Utilization: A Vital and Effective Pathway for Decarbonization*, e.d. Center for Climate and Energy Solutions (September 2019), 2, https://www.c2es.org/document/carbon-utilization-a-vital-and-effective-pathway-for-decarbonization.

83. Alan Whitehead, *Independent Review of Greenhouse Gas Removals* (October 2025), 25, https://assets.publishing.service.gov.uk/media/68fv8d27a0794bb80118bb764/independent-review-of-ggr.pdf.

84. *See* IPCC, *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* ed. Thomas F. Stocker et al. (Cambridge, UK and New York, USA: Cambridge University Press, 2013), https://doi.org/10.1017/CBO9781107415324.

85. Whitehead, *Independent Review of Greenhouse Gas Removals,* 24.

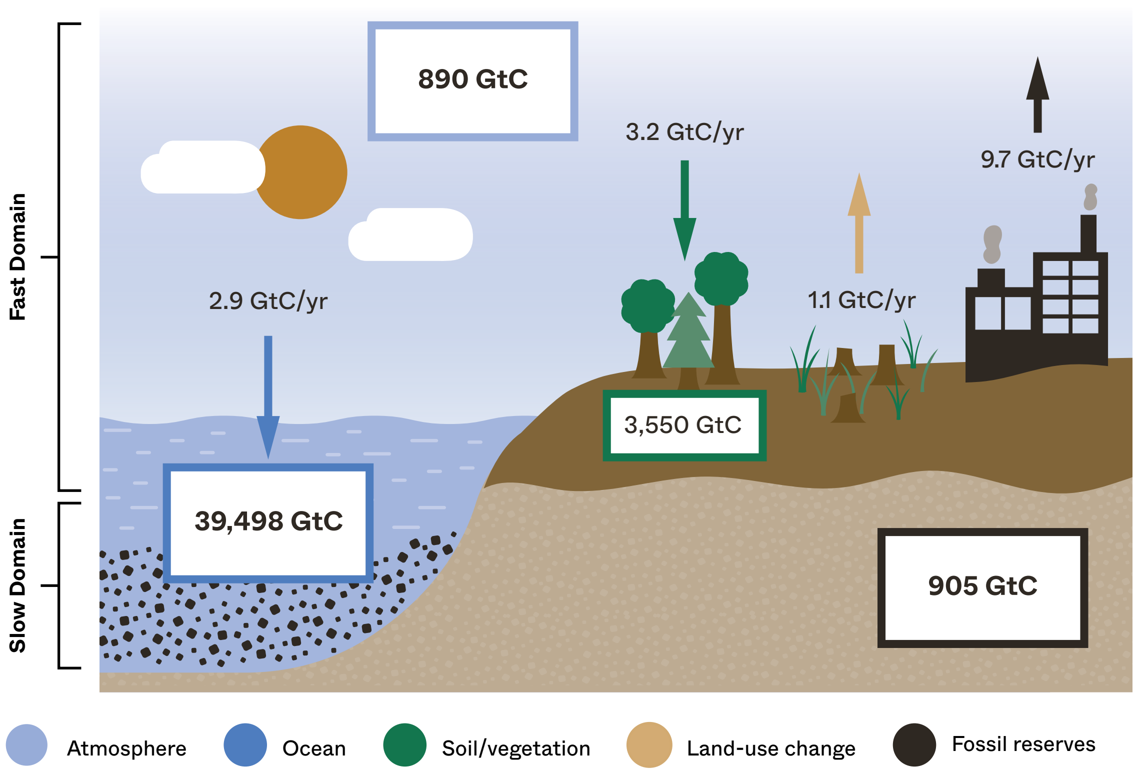

Figure 5. Rectangles show major sinks of the global carbon cycle, spanning its fast and slow domains. Arrows depict the overall disturbance of the natural global carbon cycle caused by anthropogenic activities. Values are averaged globally for the decade 2014–2023. Carbon moves throughout the fast domain within years to decades and throughout the slow domain in 10,000 years or longer. CCS and CDR with GCS can serve as counteracting fluxes to the anthropogenic release of carbon caused by combusting fossil fuels. GCS is the only way to expeditiously return emitted carbon to the slow domain. GCS is also the only pathway to GNZ—the principle that durable climate stability cannot be reached unless and until, for every MT of CO_2 released from burning fossil fuels, an equal amount is captured or removed and sequestered underground in stable rock formations.[86]

By contrast, GCS offers a verifiable and permanent solution, effectively preventing the re-release of stored carbon into the fast carbon cycle for millennia.[87] The only way to reliably and permanently compensate for legacy carbon pollution is to apply the principle of like-for-like compensation with geological storage.[88] Under this concept of Geological Net Zero (GNZ), for every ton of CO_2e still generated from fossil sources, one ton of CO_2 must be permanently restored to the solid Earth, to the slow domain.[89] Notable methods here include direct

86. Adapted from Pierre Friedlingstein et al., "Global Carbon Budget 2024," Earth System Science Data 17 (2025): 971, https://doi.org/10.5194/essd-17-965-2025; Philippe Ciais et al., "Carbon and Other Biogeochemical Cycles," in Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. T. F. Stocker et al. (Cambridge: Cambridge University Press, 2013), 470, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter06_FINAL.pdf.

87. *Id.*; Washington Climate Partnership, *Draft CCAP*, 197.

88. The like-for-like principle is defined by the United Nations Framework Convention on Climate Change as "when a source of emissions and an emissions sink correspond in terms of their warming impact, and in terms of the timescale and durability of carbon storage." "How to Avoid Carbon Removal Delaying Emissions Reductions," *Carbon Gap*, accessed October 26, 2025, https://carbongap.org/how-to-avoid-mitigation-deterrence.

89. Myles R. Allen et al., "Geological Net Zero and the Need for Disaggregated Accounting for Carbon Sinks," Nature 638, no. 8050 (2025): 343–50, https://doi.org/10.1038/s41586-024-08326-8.

air carbon capture and storage (DACCS) and bioenergy with carbon capture and storage (BECCS), where the carbon is stored underground via GCS.

Modeling conducted for the State's Draft CCAP accounts for the differing timescales and durability of biological and geological carbon sequestration pathways and notes the uncertainty that exists around the availability of land-based sequestration.[90] **It concludes that of the 11.6 million MT CO_2e that will need offsetting annually to achieve net-zero emissions, at least 6.2 million MT CO_2e will need to be sequestered via GCS.[91].** (See Figure 6.) Accordingly, it is critical for the State to seek early and substantial investments and partnerships to establish an enabling environment for GCS technologies, which are necessary to achieve GNZ and the State's climate and clean energy goals.[92]

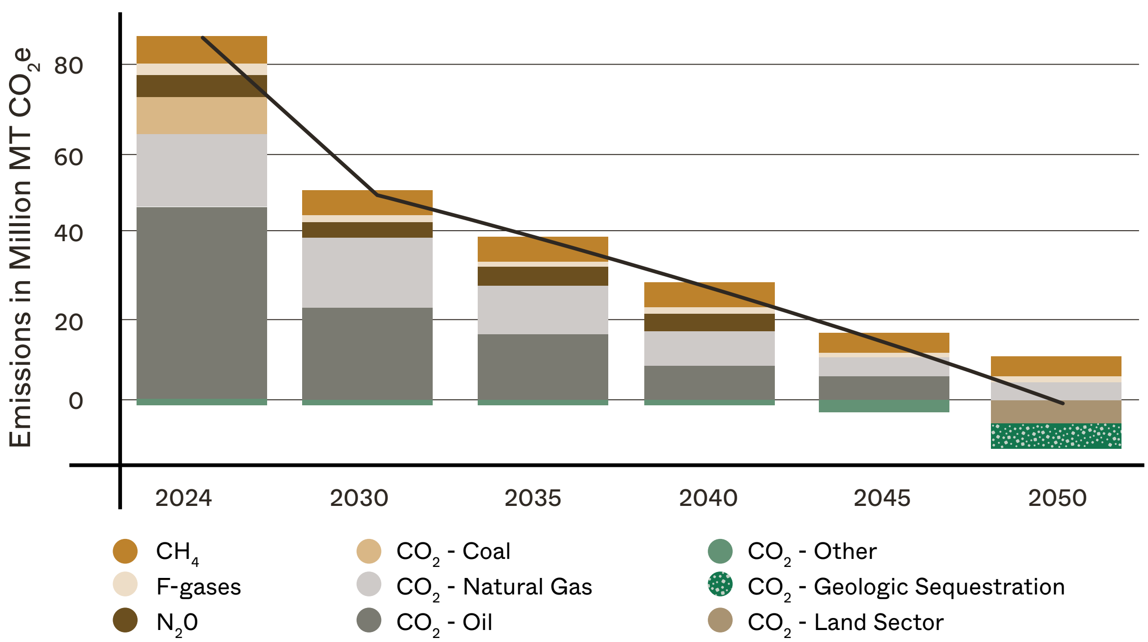

Figure 6. Washington's GHG emissions by type and source under the CCAP Scenario developed by Evolved Energy Research and CETI, which models pathways for fully meeting Washington's climate and energy mandates of an electricity supply free of GHG emissions by 2045 and net-zero emissions by 2050. No pathway to net-zero emissions by 2050 is feasible without GCS; for Washington to reach and maintain net-zero, beginning in 2050, 6.2 million MT CO_2e will need to be offset and sequestered annually via GCS.[93]

90. Evolved Energy Research and CETI, *Emissions Modeling*, 27.

91. *Id.*

92. Evolved Energy Research, *Net-Zero Northwest*, 238.

93. Adapted from Evolved Energy Research and CETI, *Emissions Modeling*, 25.

KEY TAKEAWAYS

- Washington set one of the most ambitious climate targets in the nation: delivering net-zero emissions by mid-century. The CCA, CETA, and CFS are three core laws governing the State's transition away from fossil fuels and to net-zero emissions.

- The ability of electric utilities to comply with the CCA and CETA and satisfy state climate goals depends on the availability of clean energy; however, deployment is currently behind pace and future development faces several mounting challenges.

- Delayed deployment of new clean energy projects causes Washington to increasingly face an impossible choice: temporarily suspend its clean energy mandates or risk rolling blackouts, rising prices, and public ire. But, if the need arises, the Legislature could protect and sustain CETA—could ensure a steady supply of clean firm power without compromising public support for decarbonization—by slightly modifying CETA to encourage E-NGPP utilities actively supporting development of renewable resources and nonemitting electric generation sources to retrofit existing natural gas power plants far from end-of-life with CCS and maintaining them temporarily, until renewable capacity satisfies demand and supports a carbon-free grid. If CETA is modified in this way, the Legislature should set a retirement date for these plants so that CCS mitigates fossil fuel use but does not facilitate prolonged use.

- Hard-to-decarbonize industrial sources require CCS. Capturing and sequestering CO_2 emissions at these facilities, once a protocol is developed, provides perhaps the only appreciable compliance pathway to net zero.

- Deploying CCS between now and mid-century presents an opportunity to begin building the infrastructure and expertise that the State will need to offset residual emissions with CDR+S. Notable methods include DACCS and BECCS, where the carbon is stored underground via GCS.

- GCS is a superior, permanent form of containment because it prevents the re-release of stored carbon into the fast carbon cycle for millennia. Of the 11.6 million MT CO_2e emissions released annually in the State that will need offsetting via CDR+S beginning in 2050, at least 6.2 million MT CO_2e will need to be sequestered annually via GCS.

3. Injection Techniques and Mineralization Science

RECAP FROM PRIOR CHAPTERS

- CCS and CDR+S are critical components of Washington's decarbonization strategy; the State cannot otherwise reach net-zero emissions by 2050.
- GCS is a more reliable and permanent sequestration solution than carbon utilization or sequestration in biological systems because GCS returns CO_2 to the slow carbon cycle.
- Starting in 2050, Washington will need to sequester at least 6.2 million MT CO_2e each year through GCS.

Injection Techniques and Mineralization Science

Carbon Mineralization

Carbon mineralization is a chemical process in which CO_2 dissolved in water reacts with silicate minerals in rocks to form carbonate minerals—trapping carbon in the solid rock matrix.[94] The reaction occurs naturally at Earth's surface in some locations, with CO_2 being absorbed from the atmosphere, and can be stimulated to occur in the subsurface by injecting CO_2 into certain geologic formations.[95] Laboratory and field experiments have shown that the reaction is especially effective in porous and permeable rocks rich in calcium, magnesium, and iron. (See Figure 7.) These elements are abundant in minerals making up the massive basalt formations of the CRBG, which underlies most of Washington.

Figure 7. Core from a well near Wallula in southeastern Washington showing calcium carbonate nodules (light color) resulting from carbon mineralization. The core sample was taken from a well two years after 977 MT CO_2 were injected into the Grande Ronde basalt at a depth of nearly one kilometer, or 3,281 feet, during the summer of 2013. The light areas show portions of the rock where calcium carbonate minerals have replaced the original basaltic minerals.[96]

Natural carbon mineralization helps regulate Earth's global temperature over geologic time by preventing a runaway greenhouse effect leading to uncontrollable warming. But this process—which unfolds over thousands of years—is not rapid enough to balance the large fluxes of anthropogenic CO_2 entering the atmosphere from burning fossil fuels. Engineered carbon mineralization accelerates this natural process, providing a durable pathway for climate mitigation.

Injecting CO_2 in large quantities underground is not new. Petroleum companies inject CO_2 into depleted reservoirs to enhance recovery of oil and gas, in a process typically referred to as Enhanced Oil Recovery (EOR). CO_2 is also injected into depleted petroleum reservoirs and deep saline aquifers for GCS. These two conventional methods rely soley on an impermeable caprock as an indefinite structural trapping mechanism to inhibit the migration of buoyant CO_2 to the surface.[97] **In contrast, injecting CO_2 for GCS into certain types of basalt formations, like the CRBG,**

94. A typical reaction is one in which a calcium-rich form of the mineral pyroxene, which is abundant in the basalts of the CRBG, reacts with CO_2 in water to form quartz and limestone (calcium carbonate). Chemists write the net reaction as: $CaSiO_3$ *(pyroxene)* + CO_2 + H2O → SiO_2 *(quartz)* + $CaCO_3$ *(limestone)* + H_2O. Although water is not consumed in the reaction, it is necessary for the reaction to take place.

95. *See* Henry Fountain, "How Oman's Rocks Could Help Save the Planet," Climate, *The New York Times*, April 26, 2018, https://www.nytimes.com/interactive/2018/04/26/climate/oman-rocks.html.

96. PNNL, "Carbon Dioxide Tucked into Basalt Converts to Rock," posted on November 18, 2016, Youtube, 00:11, https://www.youtube.com/watch?v=4IUQn9uL6W0.

97. Snæbjörnsdóttir et al., "Carbon Dioxide Storage through Mineral Carbonation," 92.

benefits from a second trapping mechanism: carbon mineralization. Injecting into basalt is therefore superior to—safer and more permanent than—these conventional methods of CO_2 injection.

Not all basalt formations are suitable for CO_2 injection. In fact, most basalts are highly impermeable to fluid injection and flow. But, the flood basalts of the CRBG are composed of multiple stacked, thick, and laterally extensive flows. Porous and permeable vesicular flow tops are usually bounded by impermeable basalt layers up to 100 meters (m) thick. These bounded flow tops, combined with the flow bottom of an overlying flow, are ideal candidates for CO_2 injection—for safe and permanent GCS by carbon mineralization.[98]

Chapter 7: Geologic Setting provides detailed information about the CRBG's structure.

Field trials show that two injection techniques can safely and permanently sequester CO_2 in basalt. The Wallula Basalt Pilot Project, a pioneering experiment conducted in 2013 by Pacific Northwest National Lab (PNNL) of the U.S. Department of Energy (USDOE) in a well near Wallula, demonstrated that carbon mineralization can proceed rapidly in the CRBG.[99] (See

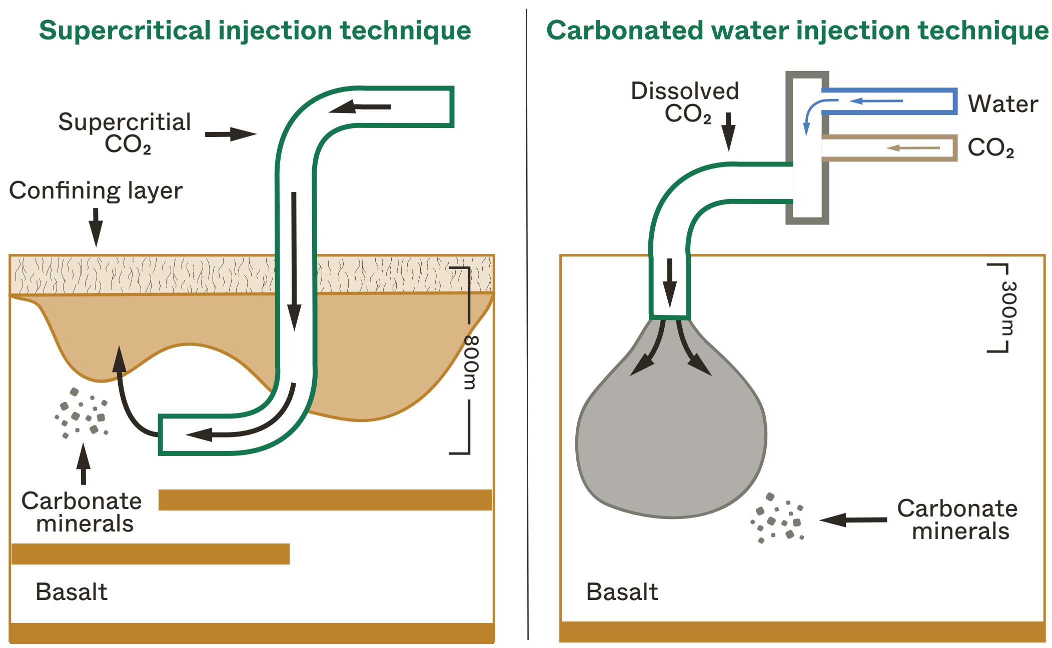

Figure 8. Two techniques for in-situ carbon mineralization: supercritical CO_2 and carbonated water. 300 m is approximately 984 ft; 800 m is approximately 2,625 ft.[100]

98. *See, e.g.*, International Energy Agency, *Geologic Storage of CO_2 in Basalts* (2011), 4, 11.

99. "Wallula Basalt Project," PNNL, accessed October 7, 2025, https://www.pnnl.gov/projects/carbon-storage/wallula-basalt-project.

100. Adapted from Snæbjörnsdóttir et al., "Carbon Dioxide Storage through Mineral Carbonation," 95.

Figure 8.) CO_2 was compressed into its supercritical state at the surface and injected directly into the Grand Ronde basalt formation at depth. Most of the CO_2 mineralized within two years.[101] More recent experiments in Iceland, carried out by the company Carbfix, have shown that gaseous CO_2 can be mixed with water at the surface, creating a carbonated-water stream, which can be injected at shallower depths to achieve similar results.[102]

Supercritical CO_2 Injection

Supercritical CO_2 is a liquid-like state of CO_2 that results when the gas is compressed to pressures of approximately 73 atmospheres at temperatures above 30°C. Although much denser than the gaseous phase, supercritical CO_2 is still buoyant in groundwater, and its low viscosity allows efficient flow through underground pore spaces.

Supercritical CO_2 must be injected at depths below 800 m, or approximately 2,623 feet (ft), where pressure and temperature maintain the supercritical state. High permeability of the geologic formation is critical to ensuring the reservoir's capacity to sustain injection of fluid over long periods of time.[103] Equally important is thick, continuous caprock preventing upward leakage of the buoyant fluid until the carbon is mineralized into the rock matrix. The structural 'geologic traps' of conventional petroleum reservoirs, with natural barriers to upward and lateral flow, are generally favored for this injection technique.[104]

PNNL carried out the first carbon mineralization experiment in basalt using supercritical CO_2. The Wallula Basalt Pilot Project injected 977 MT CO_2 into the CRBG, specifically into a flow top of the Grande Ronde basalt, at depths between 830 and 890 m (≈2,723–2,920 ft). Two years later, the carbonate mineral ankerite, which was not present in pre-injection drilling cores, was found in post-injection cores, demonstrating successful carbon mineralization.[105] (See Figure 7.) PNNL estimates that approximately 65% of the injected CO_2 was mineralized during the two years between injection and sampling, with the new minerals occupying only 4% of the formation's available pore space. This finding suggests that the flow top accessed by the Wallula Basalt Pilot Project well could sequester an additional 16,000 MT CO_2.[106] Later borehole monitoring detected no leakage, confirming a safe and permanent trial.

Carbonated Water Injection

The carbonated water injection technique dissolves CO_2 into a large volume of water under pressure to create a dense, non-buoyant solution for underground injection. Carbonated water can be injected at shallower depths than supercritical CO_2 and into basalt formations

101. Signe K. White et al., "Quantification of CO_2 Mineralization at the Wallula Basalt Pilot Project," *Environmental Science & Technology* 54, no. 22 (2020): 14609–16, https://doi.org/10.1021/acs.est.0c05142.

102. Snæbjörnsdóttir et al., "Carbon Dioxide Storage through Mineral Carbonation," 95.

103. Catherine Callas et al., "Criteria and Workflow for Selecting Depleted Hydrocarbon Reservoirs for Carbon Storage," *Applied Energy* 324, no. 119668 (October 2022), https://doi.org/10.1016/j.apenergy.2022.119668.

104. *See* Muhammad Hammad Rasool et al., "Selecting Geological Formations for CO_2 Storage: A Comparative Rating System," *Sustainability* 15, no. 8 (2023): 6599, https://doi.org/10.3390/su15086599.

105. White et al., "Quantification of CO_2 Mineralization at the Wallula Basalt Pilot Project," 14609–16.

106. *Id.*

with lower permeability, because the pre-mixed, acidic solution will partially dissolve basalt minerals, thereby creating more pore space and promoting rapid mineralization. Carbonated water behaves much like ordinary groundwater, moving predictably through underground pore spaces.[107] The main drawback of this technique is the large volume of water—a mixture of approximately 25 parts water to one part CO_2—needed to create the carbonated flow stream.[108]

Carbonated water injection is well-suited to the shallow vesicular flow tops of the CRBG, which offer abundant surface area for reaction.[109] Because carbonated water is not buoyant, impermeable caprock above the injection layer is desirable but not strictly necessary to provide a barrier to groundwater mixing driven by pressure differences. Nevertheless, in the CRBG, thick, impermeable entablature layers naturally bound the permeable flow tops.

The startup company Carbfix has studied carbon mineralization in basalts by dissolving CO_2 in freshwater prior to injection into the oceanic basalt formations forming the Mid-Atlantic Ridge, which is exposed in Iceland. Carbfix reports that, based on its monitoring, more than 95% of the injected gas mineralizes within two years.[110] Carbfix began as a research project at the University of Iceland and conducted its first pilot injection in 2012. The company, which was incorporated as a subsidiary of Reykjavik Energy in 2019, has developed the world's first commercial in-situ carbon mineralization operations, facilitated by a public-private partnership (P3) model. Today, Carbfix mineralizes approximately 33 MT CO_2 each day at its first project site.[111]

Carbfix is testing the use of seawater for CO_2 mixing and injection through a project called "CO_2 SeaStone."[112] Carbfix mixes seawater from the North Atlantic Ocean with CO_2 captured locally and injects the mixture into Mid-Atlantic Ridge basalts on land. Early results have been positive, showing little variation from freshwater carbonation. Using saline water for carbonated water injection and mineralization has obvious advantages in areas where freshwater is scarce or in high demand for irrigation and consumption.

Table 1 compares these two techniques, supercritical and carbonated water injection, against a collection of practical metrics relevant to large-scale implementation of GCS in the CRBG.

107. In carbonated water injection, CO_2 is dissolved rather than free, avoiding gravity segregation and improving sweep efficiency compared with supercritical CO_2 injection. Mehran Sohrabi et al., "Carbonated Water Injection (CWI)–A Productive Way of Using CO_2 for Oil Recovery and CO_2 Storage," *Energy Procedia*, 10th International Conference on Greenhouse Gas Control Technologies 4 (January 2011): 2192–99, https://doi.org/10.1016/j.egypro.2011.02.106.

108. Snæbjörnsdóttir et al., "Carbon Dioxide Storage through Mineral Carbonation," 95.

109. *See* Wei Xiong et al., "CO_2 Mineral Trapping in Fractured Basalt," *International Journal of Greenhouse Gas Control* 66 (November 2017): 204–17, https://doi.org/10.1016/j.ijggc.2017.10.003.

110. Juerg M. Matter et al., "Rapid Carbon Mineralization for Permanent Disposal of Anthropogenic Carbon Dioxide Emissions," *Science* 352, no. 6291 (2016): 1312–14, https://doi.org/10.1126/science.aad8132.

111. Helga Kristjánsdóttir and Sigríður Kristjánsdóttir, "Carbfix and Sulfix in Geothermal Production, and the Blue Lagoon in Iceland: Grindavík Urban Settlement, and Volcanic Activity," *Baltic Journal of Economic Studies* 7, no. 1 (2021): 1–9, https://doi.org/10.30525/2256-0742/2021-7-1-1-9; Juerg M. Matter et al., "The CarbFix Pilot Project–Storing Carbon Dioxide in Basalt," Energy Procedia 4, 10th International Conference on Greenhouse Gas Control Technologies (January 2011): 5579–85, https://doi.org/10.1016/j.egypro.2011.02.546.

112. Sandra Snæbjörnsdóttir et al., "Seastone: The First Injection of Seawater-Dissolved CO_2 into Reactive Basalt," *Geological Society of America Abstracts with Programs* 56, no. 4 (May 2024), https://doi.org/10.1130/abs/2024CD-399614.

Table 1. Comparison of Supercritical vs. Carbonated Water Injection Parameters

Parameter	Supercritical CO_2	Carbonated Water
Energy Demand	Moderate: Required for compression to supercritical state	High: Required for dissolving CO_2 and pumping larger volumes
Depth	≥800 m (≈ 2,625 ft)	400–800 m (≈ 1,312–2,625 ft)
Water:CO_2 mass ratio	Low: ~ <1:1 within pore space	High: ~ 25:1
Mineralization in two years	65% (estimated)	95% (estimated)
Hydrogeologic properties required	Strong caprock; High porosity and permeability in reservoir	Caprock desirable; Lower porosity and permeability in reservoir
Safety rating	Moderate: Buoyant CO_2 poses risk of upward migration	High: CO_2 is already dissolved, minimizing leakage risk
Monitoring requirements	Plume tracking and leak detection needed	Less monitoring might be possible (if supported by regulation) due to faster mineral trapping
Transportation requirements	Transportation of supercritical CO_2 (via pipeline)	Transportation of supercritical CO_2 (via pipeline) or liquid CO_2 (via truck or ship) plus large volumes of water
Surface footprint	2–5 acres	2–5 acres

Projects in the Pipeline

Despite the clear benefits of carbon mineralization, storage of CO_2 in basalts remains underdeveloped in the U.S. compared with storage in depleted petroleum reservoirs and saline aquifers. Around the world, however, momentum is growing to test carbon mineralization in basalt at larger scales. For example, Cella plans to test the technique of water-alternating-gas

(WAG) injection in the basalt formations in the East African Rift.[113] WAG injection, which proceeds exactly as the acronym describes, has become a standard method of improving EOR in giant carbonate reservoirs of the Middle East, which have complex pore structures resembling that of vesicular basalts.[114] The company 44.01 has successfully mineralized CO_2 in peridotite (a source rock of basalt) using seawater, in a test carried out in the United Arab Emirates.[115] Finally, Solid Carbon has studied the feasibility of sequestering 50 MMT CO_2 in oceanic basalt off the coast of British Columbia and Washington (beyond state waters) and is developing a proposal for a pilot injection project.[116]

Given the similarities between the CRBG and other basalt provinces around the world, results from all of these projects will be relevant to developing a sound technical and economic GCS strategy for Washington on a time scale responsive to the climate crisis.

KEY TAKEAWAYS

- Injecting CO_2 into basalt for GCS provides superior containment compared to conventional methods, as the CO_2 rapidly mineralizes into solid rock, ensuring permanent sequestration.
- The CRBG's vesicular flow tops, usually bounded by impermeable basalt layers hundreds of meters thick, are ideal candidates for permanent GCS by carbon mineralization.
- Field trials show that two injection techniques can safely and permanently sequester CO_2 in basalt: the supercritical injection technique and the carbonated water injection technique.
- Carbonated water can be injected at shallower depths than supercritical CO_2 and into basalt formations with lower permeability; however, a significant volume of water is required.
- Carbon mineralization projects worldwide are advancing from field tests to large-scale demonstrations, highlighting increasing confidence in and momentum for storing CO_2 in basalt.
- Despite the clear benefits of carbon mineralization, storage of CO_2 in basalts remains underdeveloped in the U.S., and specifically in Washington, compared with storage in depleted petroleum reservoirs and saline aquifers.

113. "Cella Mineral Storage," Cella Mineral Storage, accessed July 15, 2025, https://www.cellamineralstorage.com.

114. *See* George Otieno Okoko and Lydia A. Olaka, "Can East African Rift Basalts Sequester CO_2? Case Study of the Kenya Rift," *Scientific African* 13, no. e00924 (September 2021), https://doi.org/10.1016/j.sciaf.2021.e00924.

115. "About Us," 44.01 Earth, accessed September 12, 2025, https://www.4401.earth/about-us; *see also* Sasha Ranevska, "ADNOC And 44.01 Ready To Scale CO_2 Mineralization After A Successful Pilot Run," *Carbon Herald*, November 2024, https://carbonherald.com/adnoc-and-44-01-ready-to-scale-CO_2-mineralization-after-a-successful-pilot-run.

116. "About Solid Carbon," Solid Carbon, accessed July 15, 2025, https://solidcarbon.ca.

4. Project Development Hurdles

RECAP FROM PRIOR CHAPTERS

- The CRBG has great potential to sequester and lock away up to 40 billion MT CO_2 for millennia.
- Field trials indicate that two injection techniques—supercritical injection and carbonated water injection—can safely and permanently sequester CO_2 in basalt.
    - The Wallula Basalt Pilot Project, a research study led by PNNL that injected supercritical CO_2 into a well in 2013, demonstrated that carbon mineralization can occur rapidly in the CRBG.
    - Carbfix deploys the carbonated water injection technique, which dissolves CO_2 into a large volume of water under pressure before injection, at commercial-scale in Iceland.
- Despite the clear benefits of carbon mineralization, storage of CO_2 in basalts remains underdeveloped compared with storage in depleted petroleum reservoirs and saline aquifers.

Project Development Hurdles

Project developers seeking to develop first-of-a-kind GCS projects in Washington's basalt formations face significant regulatory, social, technological, and financial hurdles compared to those developing GCS projects in conventional sequestration reservoirs.[117] These hurdles may be too overwhelming or discouraging unless the State helps to reduce their scale.

In the decade since PNNL first validated rapid mineralization and permanent storage of CO_2 in basalt during its field trial near Wallula, no GCS projects have progressed in the State, despite its promise to be a global GCS hub. Even feasibility studies throughout the region have been lacking, with few exceptions. Ongoing, completed, potential, and canceled studies at the time of drafting include:

- **Washington TrapRock Geophysical Research Surveys:** an ongoing geophysical remote sensing project mapping the subsurface below southern Benton County and parts of Klickitat and southeastern Yakima counties, led by the Carbon Containment Lab and supported by funding from Washington's CCA;[118]

- **Solid Carbon:** a feasibility study assessing the suitability of an ocean basalt reservoir for GCS in the Cascadia Basin offshore from British Columbia and Washington State but beyond state waters, which was completed in 2024;[119]

- **Grays Harbor CO_2 Capture and Storage Hub Project:** a forthcoming study designed to explore the potential of storing 50 million MT CO_2 within a 30-year timeframe in a geologic storage complex in Grays Harbor County that was awarded federal CarbonSAFE funding by the USDOE, which is understood to be delayed;[120]

- **HERO Basalt Project:** a forthcoming CCS feasibility study at a gas-fired power station south of Hermiston, Oregon that was awarded federal CarbonSAFE funding but which has been delayed;[121]

- **SHINE CarbonSafe:** a forthcoming study assessing the feasibility of sequestering CO_2 emissions captured from gas pipeline compressor stations in southeastern Washington, the federal funding for which has been delayed;[122]

117. *See, e.g.*, Washington Climate Partnership, *Draft CCAP*, at 107.

118. "Washington TrapRock Geophysical Research Surveys," Washington TrapRock GRS, accessed October 2, 2025, https://www.watraprocksurveys.org. DNR is a participant in this and other feasibility studies.

119. David Goldberg et al., "Integrated pre-feasibility study for CO_2 geological storage in the Cascadia Basin, offshore Washington State, British Columbia" (2018), https://doi.org/10.2172/1488562; *see also* "About Solid Carbon."

120. "Projeo Corporation Selected by U.S. Department of Energy for CarbonSAFE Storage Complex Feasibility Project," Projeo Corporation, December 10, 2024, https://www.projeo.com/news/projeo-selected-for-carbonsafe-storage-complex-feasibility-project; *see also* National Energy Technology Laboratory, "CarbonSafe Initiative," USDOE, accessed November 8, 2025, https://netl.doe.gov/carbon-management/carbon-storage/carbonsafe.

121. J. Fred McLaughlin et al., "HERO CarbonSAFE Phase 2 Project in the Columbia River Basalt Group," *17th International Conference on Greenhouse Gas Control Technologies* (2024), https://doi.org/10.2172/2475149.

122. "Project Selections for FOA 2711: Carbon Storage Validation and Testing (Round 3)," USDOE, accessed November 19, 2025, https://www.energy.gov/fecm/project-selections-foa-2711-carbon-storage-validation-and-testing-round-3.

- **CaRBTAP:** an intended three-year initiative that would provide objective and unbiased technical support for carbon management and storage projects in the Pacific Northwest, which is stalled while awaiting delayed federal funding;[123] and

- **Ankeron Carbon Management Hub:** a feasibility study of a regional DACCS hub in the TriCities region, which was terminated.[124]

In contrast, large-scale commercial GCS projects are underway or actively pursuing permits in Alabama, Arkansas, California, Florida, Illinois, Indiana, Kansas, Louisiana, Michigan, Nebraska, New Mexico, North Dakota, Ohio, Osage Nation, Texas, West Virginia, and Wyoming.[125] This dissimilitude is due to the fact that GCS project developers interested in utilizing Washington's basalt resources face several siting, regulatory compliance, and other challenges unique to being a first mover. They are also impeded by the fact that Washington has not yet adopted comprehensive GCS legislation.

Chapter 12: Recommended Next Steps sets forth proposed solutions and immediate action items. A P3 can overcome these challenges.

Siting Challenges

Injection Well Siting

Globally, storage of CO_2 in basalts via mineralization is less well-studied than storage in sedimentary rocks.[126] Locally, Washington's subsurface is less well-studied compared to that of states with commercial oil and gas production. Whereas most of Washington's geology and deep hydrogeology remain unmapped, decades of oil and gas operations in the Gulf Coast and Permian Basin, for example, have produced extensive geological data pertinent to identifying sites ideal for injecting and storing CO_2. Because GCS project developers interested in Washington currently have a relative paucity of geophysical data publicly available to inform their injection siting decisions, they must gather detailed site information themselves, increasing the time and expense of siting and project development.

This lack of subsurface data also inhibits development of a statewide GCS siting strategy, and the absence of such a strategy makes engagement with rightsholders and stakeholders more challenging for GCS project developers. Federally-recognized Indian Tribes with reservations, ceded territories, and/or other Tribal interests overlying potential sequestration sites within

123. "Pioneering Carbon Management in the Columbia River Basalt," Columbia River Basalt Technical Assistance Partnership, accessed October 2, 2025, https://www.carbtap.com.

124. Daniel Pike, "Ankeron: A DAC Hub Study in the Pacific NW," slides presented at 2024 DOE FECM/NETL Carbon Management Research Project Review Meeting, August 7, 2024, https://netl.doe.gov/sites/default/files/netl-file/24CM/24CM_CDR_7_Pike.pdf.

125. "Current Class VI Projects under Review at EPA," USEPA, last modified on September 30, 2025, https://www.epa.gov/uic/current-class-vi-projects-under-review-epa.

126. *See* Jennifer Pett-Ridge et al., *Roads to Removal: Options for Carbon Dioxide Removal in the United States* (Lawrence Livermore National Laboratory, 2024), 4-4, https://roads2removal.org.

the CRBG in Washington most likely include the Coeur d'Alene Tribe, the Confederated Tribes and Bands of the Yakama Nation, the Confederated Tribes of the Colville Reservation, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation, the Cowlitz Indian Tribe, the Kalispel Tribe of Indians, the Nez Perce Tribe, and the Spokane Tribe of Indians. Additionally, the Wanapum Band of Native Americans have traditional lands and interests in the CRBG in Washington. Above all, the State and GCS project developers each must respect the sovereign rights of these Indian Tribes who have stewarded Washington's lands and waters since time immemorial. Respect is demonstrated, in part, by meaningful government-to-government consultation and by early and often engagement by project developers, to ensure that a project proceeds with Tribal input and that it will not adversely impact Treaty rights or cultural resources.

Because there is no comprehensive understanding of the State's basalt formations, it is unconfirmed which formations could best support safe and permanent GCS. Lacking this information, no meaningful government-to-government consultation about a GCS siting strategy has or could have occurred. It also has not been possible to consider input from, and potential impacts upon, other overburdened communities or vulnerable populations within the CRBG. The Indian Tribes with reservation or traditional lands overlying potential sequestration sites within the CRBG, local communities within the CRBG, and GCS project developers are expected to find that siting discussions are more time-consuming and involve incomplete information, until such a data-informed strategy is prepared. Streamlining outreach and engagement to inform site selection will be a critical component of transitioning the State into a global GCS hub.

Chapter 9: Siting Prioritization identifies—for the first time—state trust lands within three regions of the CRBG as those best suited for future GCS exploration. Consideration of Tribal Treaty rights and cultural resource practices informs the ranking of these regions. Further study and government-to-government consultation will be required to refine GCS siting.

Pipeline Siting and Safety

CO_2 can be transported via truck, rail, ship, or pipeline, though pipelines are considered the most efficient, cost-effective, and safest method.[127] There are over 5,000 kilometers (km), or 3,107 miles, of pipeline throughout the U.S. transporting more than 40 $MTCO_2$ per year, typically in supercritical phase and mostly to sites in Texas, where CO_2 is commonly injected for EOR.[128]

127. "Carbon Dioxide Transport 101," Great Plains Institute, last modified February 14, 2023, https://betterenergy.org/blog/carbon-dioxa ide-transport-101/#:~:text=There%20are%20many%20ways%20to,of%20miles%20across%20entire%20regions.

128. Paul W. Parfomak, *Siting Challenges for Carbon Dioxide (CO_2) Pipelines*, ed. Congressional Research Service (2023), 1, https://www.congress.gov/crs_external_products/IN/PDF/IN12269/IN12269.2.pdf; Working Group III of the IPCC, *IPCC Special Report on Carbon Dioxide Capture*

Washington has no pipelines transporting CO_2. CDR facilities ideally will be sited on or adjacent to state trust lands with injection wells. Still, project developers may need to construct new pipelines to transport CO_2 from facilities capturing CO_2 to sequestration sites. Serious gaps in oversight of pipeline siting and safety at both the federal and state level complicate this task.

If a pipeline crosses state lines, then federal jurisdiction is implicated. However, both federal agencies with potential oversight of siting CO_2 pipelines, the Federal Energy Regulatory Commission and the Surface Transportation Board, have disclaimed that authority.[129]

The Pipeline and Hazardous Materials Safety Administration (PHMSA) has authority to regulate the safety of CO_2 pipelines, specifically construction, operation, and maintenance.[130] So far, PHMSA has adopted only regulations applicable to CO_2 in its supercritical form, and these regulations are considered outdated, especially so after a CO_2 pipeline exploded in 2020 near Satartia, Mississippi.[131] PHMSA in January 2025 issued a notice of proposed rulemaking prescribing new minimum safety standards for the transportation of CO_2 in supercritical form, as well as liquid and gaseous phases, but the agency subsequently withdrew the draft rule before publication under a new presidential administration.[132] PHMSA later published an advance notice of proposed rulemaking broadly soliciting "stakeholder feedback on whether to repeal or amend" any of its pipeline safety requirements.[133] How PHMSA will proceed is uncertain.

Washington has jurisdiction over certain intrastate aspects of CO_2 pipelines; this jurisdiction does not currently extend to siting. The Washington State Energy Facility Site Evaluation Council's (EFSEC's) jurisdiction is limited to petroleum, natural gas, and synthetic fuel gas pipelines, and the Washington Utilities and Transportation Commission (UTC) does not oversee pipeline siting.[134]

The UTC's role is limited to pipeline safety. The UTC's Pipeline Safety Program inspects the intrastate portion of interstate pipelines for compliance with PHMSA's regulations. The UTC has delegated authority over pipelines transporting CO_2 in liquid phase; however, the UTC does not have clear authority when CO_2 is transported in gaseous or supercritical phases.[135]

and Storage, ed. Bert Metz, Ogunlade Davidson, Heleen de Coninck, Manuela Loos and Leo Meyer (Cambridge University Press, UK, 2025), 41, https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_wholereport-1.pdf.

129. Martin Lockman, *Permitting CO_2 Pipelines* (Sabin Center for Climate Change Law, September 2023), 9–10, https://scholarship.law.columbia.edu/sabin_climate_change/207.

130. 49 C.F.R. §§ 190, 195–199.

131. *Id*. § 195.2.

132. "Carbon Dioxide (CO_2) Pipelines: Safety, Siting, and Eminent Domain," Library of Congress, effective June 2025, https://www.congress.gov/crs-product/IN12575; *see also* "USDOT Proposes New Rule to Strengthen Safety Requirements for Carbon Dioxide Pipelines," USDOT, last modified January 15, 2025, https://www.transportation.gov/briefing-room/usdot-proposes-new-rule-strengthen-safety-requirements-carbon-dioxide-pipelines.

133. Pipeline Safety: Safety of Carbon Dioxide and Hazardous Liquid Pipelines, Pipeline & Hazardous Materials Safety Administration (January 2025) (to be codified at 49 C.F.R. pts. 190, 195, 196, & 198), https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2025-01/PHMSA%20Notice%20of%20Proposed%20Rulemaking%20for%20CO2%20Pipelines%20-%202137-AF60.pdf; *see generally* Pipeline Safety: Mandatory Regulatory Reviews To Unleash American Energy and Improve Government Efficiency, Pipeline & Hazardous Materials Safety Administration, 90 Fed. Reg. 23660 (June 4, 2025).

134. RCW 80.50.020(29).

135. RCW 81.88.010(5)(b), (6); Washington Administrative Code (WAC) 480-75-100 ; *see also* 49 U.S.C. § 60105 (certification process).

In sum, there are serious gaps in CO_2 pipeline siting and safety. No federal or state agency oversees pipeline siting in the State. No federal regulations enforce CO_2 pipeline safety when CO_2 is transported in its gaseous or liquid phases; PHMSA has issued regulations, albeit outdated, over supercritical CO_2 pipeline safety only. And, despite the fact that the UTC oversees CO_2 pipeline safety for compliance with federal regulations, the UTC does not have clear authority when CO_2 is transported in its supercritical phase, or its gaseous phase.

While some may see this lack of regulatory oversight as an opportunity, the makings for strong public opposition are rife.[136] Recent cancellations of CO_2 pipeline projects indicate public confidence in any new or converted CO_2 pipeline is expected to be low, at least until the State creates a working group to identify potential CO_2 transportation corridors, expands EFSEC's and UTC's jurisdictions, and drafts regulations governing CO_2 pipeline safety for all three phases of CO_2.[137]

Regulatory Compliance Challenges

The near- to medium-term permitting pathway for GCS in the CRBG is unclear. First-of-a-kind GCS project developers interested in Washington will face permitting challenges for both pilot- and commercial-scale projects.

Safe Drinking Water Act, Underground Injection Control Wells

The primary federal law governing the injection of CO_2 into the subsurface is the Safe Drinking Water Act (SDWA), which prohibits underground injection of fluids without a permit and establishes the regulatory requirements of the Underground Injection Control (UIC) program.[138] The UIC program aims to protect public health by preventing injection wells from contaminating an underground source of drinking water (USDW). "USDW" means all or part of an aquifer that (1) supplies any public water system or (2) contains a sufficient quantity of groundwater that it could supply a public water system and either currently supplies drinking water for human consumption or contains fewer than 10,000 mg/L total dissolved solids (TDS).[139] The program is divided into six injection well classes.[140]

Well Classes

Classes II, V, and VI are pertinent here. (See Figure 9.) Class II wells are used to inject fluids associated with oil and natural gas production, such as for EOR, including when commingled with certain wastewaters.[141] These wells must inject into a formation that "is separated from any USDW by a confining zone that is free of known open faults or fractures within the area

136. Parfomak, *Siting Challenges for CO_2 Pipelines*, 1–3.

137. *Id*.; Washington Climate Partnership, *Draft CCAP*, 109; *see, e.g.*, California SB N. 614 (2025) (directing the state to adopt regulations governing CO_2 pipeline safety that are at least as protective as the draft federal regulations set forth in the unofficial version of the notice of proposed rulemaking issued by PHMSA under the Biden Administration).

138. 42 U.S.C. § 300f *et* seq. (1974).

139. 40 C.F.R. § 146.3; Washington Administrative Code (WAC) 173-218-030 (USDW means groundwaters "that contain fewer than 10,000 mg/L of [TDS] and/or supplies drinking water for human consumption.").

140. *See generally* 40 C.F.R. Part 146.

141. 40 C.F.R. § 146.5(b).

of review."[142] Washington has no Class II EOR wells, but it has primacy over them, except on Tribal lands.[143]

Class V wells are defined by exclusion; they are injection wells not falling within another well class.[144] This well class includes "injection wells used in experimental technologies"—meaning new technologies that have not yet been proven feasible under the conditions in which they are to be tested.[145] These include "pilot" GCS projects, but not those "testing the injectivity or appropriateness of an individual formation (e.g., as a prelude to a commercial-scale operation)."[146] The U.S. Environmental Protection Agency (USEPA) has noted that the Class V well may be appropriate for pilot-scale injections into basalt formations, particularly when done to "collect data to support a scientifically-based framework" for managing future GCS projects in these formations.[147]

Washington has primacy over Class V experimental GCS wells, except on Tribal lands.[148] These wells must obtain a state waste discharge permit.[149] The State's UIC regulation is more protective than the federal regulation, allowing a GCS well to inject directly into an aquifer only if the aquifer contains "naturally nonpotable groundwater" and "is beneath the lowermost geologic formation containing potable groundwater within the vicinity of the [GCS] project area."[150] Applicants must demonstrate certain geologic, technical, and monitoring conditions are met, though which criteria apply to a permit applicant depends on a project's scale.[151] The State limits injection in Class V pilot wells to total volumes of 1,000 MT CO_2, unless Ecology agrees a larger quantity is necessary to determine the feasibility and risks of a project.[152]

Class VI wells "are not experimental in nature [and] are used for" long-term GCS, whether the CO_2 is in gaseous, liquid, or supercritical phase.[153] Other well types may convert to Class VI wells. For example, a Class V well must be re-permitted as a Class VI well once no longer experimental and for operations at commercial scale.[154] The permitting requirements for Class VI wells are the most complex and robust of all well classes. The Class VI regulations

142. 40 C.F.R. § 146.22(2).

143. "Primary Enforcement Authority for the Underground Injection Control Program," USEPA, last modified on September 15, 2025, https://www.epa.gov/uic/primary-enforcement-authority-underground-injection-control-program-0.

144. 40 C.F.R. § 146.5(e); WAC 173-218-040(5)(a)(xv) (The following are examples of Class V injection wells that are allowed in Washington: ... [i]njection wells used to inject carbon dioxide for geologic sequestration.").

145. *Id*. §§ 146.5(e)(15), 146.3; 75 Fed. Reg. 77291, 77244–45 (December 10, 2010) (Class V experimental technology wells are those "of an experimental nature (i.e., to test [GCS] technologies and collect data).").

146. 75 FR 77244–45.

147. *Id*.; Office of Ground Water and Drinking Water, *Using Class V Experimental Technology Well Classification for Pilot Geologic Sequestration Projects — UIC Program Guidance (UICPG #83)*, ed. USEPA (2007), 2, 6, https://www.epa.gov/sites/default/files/2015-07/documents/guide_uic_carbon-sequestration_final-03-07.pdf.

148. *See* WAC 173-218-040(5)(a)(xv); "Primary Enforcement Authority," USEPA.

149. WAC 173-218-115(1)(a).

150. *Id*. at (1)(b); *see also* WAC 173-200-020(18) ("Naturally nonpotable groundwater" means groundwater that is unsuitable for drinking water because of natural groundwater quality and for which current treatment methods are considered unreasonable and impractical.); *cf*., 40 C.F.R. § 146.51(a).

151. *Id*. at (3).

152. *Id*. at (4)(b)(iii)(E)).

153. 40 C.F.R. §§ 146.5(f), 146.81(b).

154. *See, e.g*., 40 CFR 144.15 (prohibiting GCS wells that are not "experimental" from being permitted as Class V wells).

require that injections occur "below the lowermost USDW," unless an aquifer exemption is granted or a waiver is obtained.[155] Washington has not sought primacy over this class of wells. Until it does, USEPA will remain the permitting authority, and history has shown that permit processing will take longer.[156]

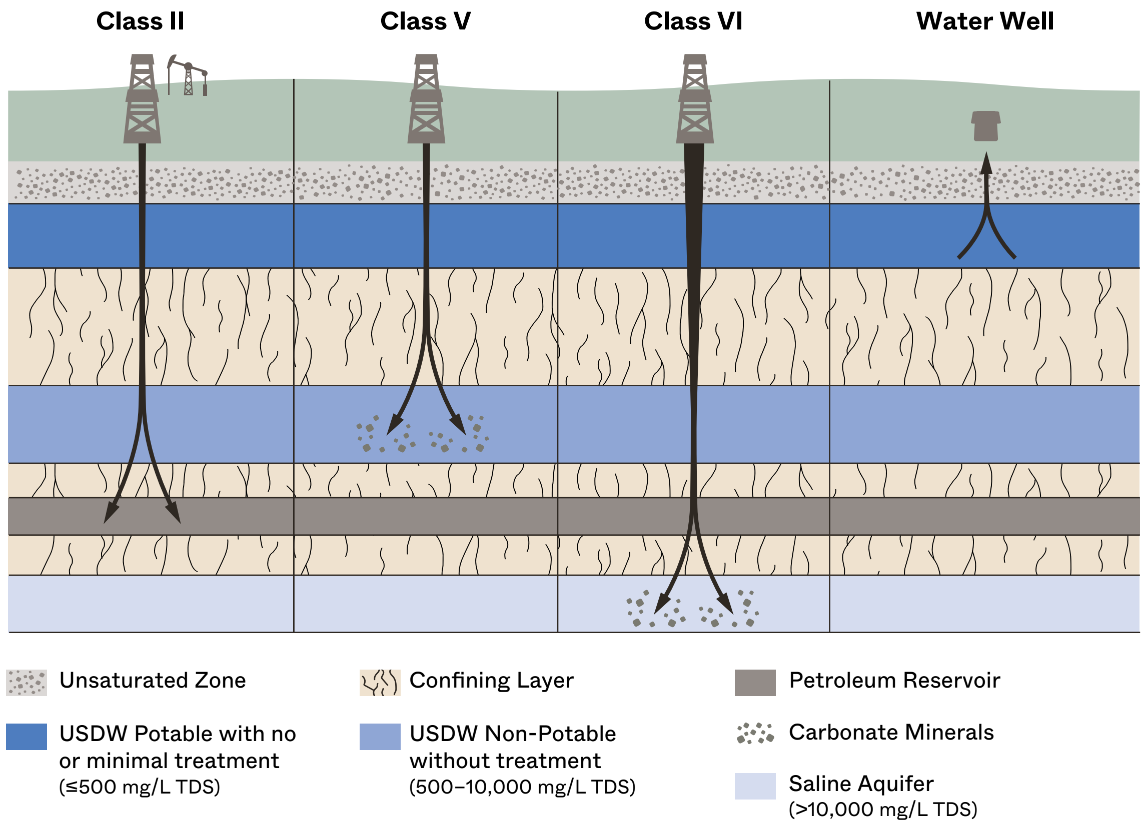

Figure 9. Depiction of well classes II, V, and VI and a water well. The subsurface presented depicts various injection zones to demonstrate regulatory differences; the subsurface is not representative of the CRBG. The UIC program of the SDWA regulates six well classes. Class II wells inject fluids associated with oil and natural gas production, such as for EOR. Class V wells include those used with experimental technologies. (The Wallula Basalt Pilot Project well was permitted by Ecology as a Class V well.) Class VI wells are used for non-experimental long-term GCS.

The Wallula Basalt Pilot Project was permitted as a Class V well by Washington's Department of Ecology.[157] Because the Wallula Basalt Pilot Project provides the sole dataset pertaining to the behavior of injected supercritical CO_2 in CRBG basalt formations, and because no data about the carbonated water technique has been collected to date, further study is required to

155. *Id*. § 146.82(d). See 40 C.F.R. § 146.95 for the requirements of obtaining a waiver.

156. *Decarbonizing the West* (Western Governors Association, 2024), 11, https://westgov.org/images/files/DTW_Initiative_Report_to_web_6_5_v2.pdf; *see also* United States Energy Association, U.S. Class VI Permitting and State Primacy (September 2025), 1, https://usea.org/sites/default/files/US%20Class%20VI%20Permitting%20and%20State%20Primacy.pdf. States with Class VI primacy include Arizona, Louisiana, North Dakota,Texas, West Virginia, and Wyoming. *Id*. Alabama, Colorado, Mississippi, Nebraska, Oklahoma, and Utah are actively pursuing it, and Oregon and several others are in the pre-application phase. *Id.; see also* "Underground Injection Control Grants," USEPA, last modified July 31, 2025, https://www.epa.gov/uic/underground-injection-control-grants.

157. *See generally* B. Peter McGrail et al., "The Wallula Basalt Sequestration Pilot Project," Energy Procedia, 10th International Conference on Greenhouse Gas Control Technologies, GHGT-10, 4 (2011): 5653-5660, https://doi.org/10.1016/j.egypro.2011.02.557.

safely develop and scale these technologies. It is expected that the first-of-a-kind small-scale limited duration pilot project using the carbonated water technique in the CRBG also will be permitted as a Class V well.

Whether the USEPA, in conversation with GCS project developers, will conclude the next several nth-of-a-kind sub-commercial GCS projects injecting into basalt qualify as pilot projects testing and refining experimental technologies—whether the USEPA will permit these wells as Class V or VI wells—depends largely on the views of the presidential administration holding office at the time permit applications are processed.[158]

If Washington obtains primacy for Class VI wells, then the determination of which well class is appropriate will belong to Ecology with consultation from the USEPA. Ecology would be the primary arbiter of GCS environmental safety in the State. Which well class is required for safe injection influences the complexity, cost, and duration of permitting and sets the conditions for whether, where, and how the supercritical CO_2 or carbonated water may be injected.

Aquifer Exemption and Depth Waiver

Federal regulations allow a USDW meeting certain criteria to be classified as an exempt aquifer, meaning injection of fluids into the aquifer is permissible. An exempt aquifer utilized for well classes I–V includes those that a permit applicant can show (1) does not serve as a source of drinking water nor can it in the future because, for example, it would be economically or technologically impractical, or (2) the TDS content of the groundwater is more than 3,000 mg/L and less than 10,000 mg/L, and the groundwater is not reasonably expected to supply a public water system.[159] Regardless, this federal exemption provision is not part of Washington's UIC program over which it has primacy, and Washington's Water Pollution Control Act, Chapter 90.48 RCW, requires protection of groundwater.[160] Accordingly, no aquifer exemption is permissible for these well classes.

The federal regulations prohibit aquifer exemptions associated with Class VI wells, except for the expansion of an existing aquifer exemption associated with a Class II EOR well converting to a Class VI well.[161] There are no EOR wells in Washington and, although EPA has approved approximately 6,500 aquifer exemptions nationwide, there are none in Washington.[162] Therefore, no exemptions associated with Class VI wells are presently permissible either and, under the current regulations, most likely never will be, because the State has no commercial oil and gas production.

The unavailability of an aquifer exemption for Class V experimental technology wells should not deter GCS project developers because state regulations authorize injection into formations that contain "naturally nonpotable groundwater;"[163] however, the unavailability

158. *See generally* Office of Ground Water and Drinking Water, *UICPG #83* (distinguishing between pilot CO_2 projects where the injection wells are regulated as Class V wells and commercial-scale projects where the wells are regulated as Class VI wells).

159. 40 C.F.R. § 146.4(a)–(c); 144.7(a), (d).

160. *See, e.g.*, WAC 173-218-030 (defining USDW with no exemption).

161. 40 C.F.R. § 146.4(a)–(c); 144.7(a), (d).

162. "Aquifer Exemptions Map," USEPA, last modified on August 13, 2025, https://www.epa.gov/uic/aquifer-exemptions-map#AE_facts.

163. WAC 173-218-115(1)(b); WAC 173-200-020(18).

of an aquifer exemption for a Class VI well could. Commercial-scale GCS projects thus must inject below the lowermost USDW—the aquifer injected into must contain more than 10,000 mg/L TDS—unless a waiver is obtained.[164] A GCS project developer may pursue a waiver of the requirement to inject below the lowermost USDW, provided that certain conditions are met, including that the injection zone itself is not a USDW and is not hydraulically connected to any USDWs.[165]

Due to a lack of geophysical data, it is presently unknown whether the CRBG possesses the conditions regulatorily required for a Class VI well. While it is not unusual for sedimentary basins to have groundwater with TDS concentrations well above 10,000 mg/L, the groundwater developed in the upper portions of the CRBG has a TDS range of approximately 150 to 400 mg/L, which falls within the potable water standard of 500 mg/L and well within the threshold of less than 10,000 mg/L TDS for classification as a USDW.[166] It is plausible that groundwaters in deeper sections of the CRBG than most water well sources in the region (e.g., 600 m [≈ 2,000 ft] or deeper) might have higher TDS concentrations. It is also plausible that injection formations in these deeper sections might be hydraulically distinct from any USDW shallower in the CRBG such that a waiver could be obtained. With that said, however, the absence of well data from these depths limits a comprehensive understanding of the region's groundwater properties and its potential for commercial-scale GCS under current regulations.[167] More information must be gathered so that the State and GCS project developers may better understand whether commercial-scale sequestration is feasible in the CRBG's deeper sections (below potable groundwater zones) under the current regulatory regime. Modification of federal and state regulations to reflect the properties of basalt formations while still protecting drinking water or establishment or a new UIC well class might be necessary.

Chapter 8: Hydrogeologic Setting presents the results of a comprehensive analysis of TDS concentrations in groundwater throughout the CRBG.

Resource Conservation and Recovery Act

Another complication arises under the Resource Conservation and Recovery Act (RCRA), which is the primary federal law governing disposal of solid waste and hazardous waste.[168] RCRA exempts from its hazardous waste regulations CO_2 "streams that are captured and transported for purposes of injection into an underground injection well subject to the requirements for

164. 40 C.F.R. §§ 146.3, 146.95; WAC 173-218-030.

165. 40 C.F.R. § 146.95(a)(1).

166. Mary Kang et al., "Deep Groundwater Quality in the Southwestern United States," *Environmental Research Letters* 14, no. 3 (2019): 034004, https://doi.org/10.1088/1748-9326/aae93c; *see also* Reuben Clair Newcomb, "Quality of the Ground Water in Basalt of the Columbia River Group, Washington, Oregon, and Idaho," in *Water Supply Paper*, nos. 1999-N (U.S. Govt. Print. Off., 1972), https://doi.org/10.3133/wsp1999N; "Secondary Drinking Water Standards: Guidance for Nuisance Chemicals," USEPA, September 2, 2015, https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals.

167. Ellen Svadlenak and Lee J. Florea, "Groundwater Chemistry in the Columbia River Basalt Group, Columbia Basin, Washington," *Washington Geological Survey Report of Investigations* 48 (2025), https://dnr.wa.gov/sites/default/files/2025-07/ger_ri48_groundwater_columbia_basin.zip.

168. 42 U.S.C. § 6901 *et seq*. (1976).

Class VI [UIC] wells[.]"[169] These streams do not qualify as hazardous waste provided certain conditions are met: the CO_2 is transported lawfully, captured from an emission source, and injected into Class VI wells for the purpose of GCS.[170] Projects involving CO_2 captured at a point source and injected into a Class V well, and CO_2 drawn down from the atmosphere and injected into either a Class V or VI well, are presently not granted this explicit exemption.

This apparent omission imposes an additional regulatory burden on pilot-scale and more climate-friendly CDR+S projects, because it creates some ambiguity around whether CO_2 qualifies as hazardous waste under RCRA. Notably, 40 C.F.R. § 144.80(e) circuitously explains that fluids designating as hazardous waste may not be injected into Class V wells—implying that CO_2, which may be injected when testing experimental technologies like carbon mineralization in basalt, does not qualify as hazardous waste and needs no exemption. Moreover, all properly permitted UIC well classes are rule authorized under the state-equivalent law that implements RCRA, the Hazardous Waste Management Act, RCW 70A.300.[171] Nonetheless, this unresolved regulatory question warrants discussion with USEPA and Ecology.

Water Right

The carbonated water injection technique presents a particular challenge: the need to obtain a water right permit for approximately 25 MT of water per ton of CO_2 sequestered.[172] A pilot-scale project injecting 1,000 MT CO_2 would need approximately 18.41 acre-feet per year (AFY), or 11.5 gallons per minute (GPM). A commercial-scale project aiming to sequester 1 million MT CO_2 per well annually using this technique would require 25 to 32 million tons of water (≈ 20,263–26,418 AFY or 23 million gallons per day [GPD]). This latter volume is utility-scale.[173]

Surface and groundwaters of the State are held in common for the public good; however, one may apply for a usufructuary water right.[174] Washington's water code follows the prior appropriation doctrine, under which senior water right holders (those "first in time" by the date the water was put to beneficial use or a water right application was submitted) have a right to use water before junior water rightholders.[175] Ecology may issue a permit for a water right if it finds that (1) water is available, (2) it will be put to a beneficial use, and (3) appropriation will not impair existing, senior rights nor (4) will appropriation be detrimental to the public welfare.[176] A transfer of an existing water right from one entity to another is also an option, and a similar analysis applies.[177]

169. 40 C.F.R. § 261.4(h).

170. 79 Fed. Reg. 350 (January 3, 2014).

171. *See* WAC 173-303-802(3).

172. Snæbjörnsdóttir et al., "Carbon Dioxide Storage through Mineral Carbonation," 95.

173. For context, the City of Tacoma's water rights total 39,000 AFY. Tacoma Public Utilities, Integrated Resource Plan (2018), 41, https://www.mytpu.org/wp-content/uploads/tacomawaterirp0219.pdf.

174. RCW 90.03.010 (surface waters); RCW 90.44.040 (groundwater). *See* Carol L. Fleskes, *Policy for the Diversion or Withdrawal of Saltwater (POL-1015)* (Olympia, Washington: Ecology, 1994), 1, https://appswr.ecology.wa.gov/docs/WaterRights/wrwebpdf/pol1015.pdf.

175. *See id.*; *Cornelius v. Dep't of Ecology*, 182 Wn.2d 574, 586, 344 P.3d 199(2015) ("Washington still follows the general prior appropriation system but has a regulatory permit scheme to balance and prioritize competing beneficial uses of the state's waters.").

176. RCW 90.03.290; *see also* RCW 90.44.030.

177. *See Burbank Irrigation Dist. No. 4 v. Dep't of Ecology*, 27 Wn. App. 2d 760, 773, 534 P.3d 833 (2023); RCW 90.44.100.

Any reduction in an existing water right holder's ability to use their entire water right, or adverse impact to an adopted instream flow or closed water body, constitutes an impermissible impairment.[178] A water right applicant may still obtain a permit if they mitigate all impairments.[179] Mitigation "must be in-time, in-place, and in-kind" and so is often costly and complicated.[180]

Ecology distinguishes between consumptive and nonconsumptive water uses when considering new water rights and transfer applications and when determining how much mitigation is required.[181] "Consumptive use" diminishes the volume or quality of a water source whereas "nonconsumptive use" does not.[182] Groundwater use is nonconsumptive when "the withdrawn water is injected or infiltrated immediately back to the aquifer."[183] Water must be returned in the same quantity and quality as it was when withdrawn.[184]

Because water availability is reduced due to climate-induced drought and water rights have been over-allocated across much of eastern Washington,[185] obtaining a new water right permit to withdraw surface water in the area of the CRBG for the carbonated water injection technique is expected to be challenging at pilot-scale volumes and impossible at commercial-scale volumes. Very little surface water remains available for appropriating in most basins and, even if it were, the mitigation required could be exorbitant.

A transfer of a surface water right is possible for a pilot-scale project but may be cost prohibitive or infeasible at commercial scale, as securing this volume would require a transfer of multiple water rights. Use of a water bank could potentially lower costs.

Obtaining a new water right permit to withdraw groundwater for GCS is expected to be challenging, if subsurface conditions support it. Any withdrawal of groundwater for industrial use exceeding 5,000 GPD will need a water right permit, so, under current designs, both pilot- and commercial-scale operations of the carbonated water injection technique would require a permit.[186] Ecology will consider the factors enumerated above and "whether a proposed groundwater project is reasonable and feasible in terms of the pumping practices to be employed."[187]

178. WAC 173-150-060; *see also Foster v. Dep't of Ecology*, 184 Wn.2d 465, 477 (2015). (Washington State's prior appropriation approach to water law does not permit any impairment, even a de minimis impairment, to a senior water right).

179. *See Foster*, 184 Wn.2d at 477 (A water right applicant must supply in-kind mitigation that mitigates the legal injury to senior water rights.).

180. Ecology, Water Right Mitigation, Publication 25-11-020 (August 2025), 2, https://apps.ecology.wa.gov/publications/documents/2511020.pdf. An example of in-kind mitigation is purchasing and relinquishing existing water rights into trust with the State.

181. WAC 173-500-050(5), (9) (defining each term); *see, e.g.*, WAC 173-501-040 (generally prohibiting new water rights applications for consumptive uses in the Nooksack River); *see also Loyal Pig, LLC v. Dep't of Ecology*, 13 Wn. App. 2d 127, 139, 463 P.3d 106 (2020) (The transfer of a water right requires Ecology to determine the annual consumptive quantity before approving a water right owner's application to change or transfer a water right.).

182. WAC 173-518-030.

183. Hedia Adelsman, *Consumptive and Nonconsumptive Water Use*, POL-1020 (Olympia, Washington: Ecology, 1991), 2, https://appswr.ecology.wa.gov/docs/WaterRights/wrwebpdf/pol1020.pdf; *cf.*, Water Resources Program Policy Support Section, *Public review draft: Consumptive and Nonconsumptive Water Use Policy and Interpretive Statement*, POL-1020, (Olympia, Washington: Ecology, 2025), 3, https://apps.ecology.wa.gov/publications/documents/2511104.pdf (to date, under public comment).

184. *Id*.

185. *See, e.g.*, *Dep't of Ecology v. Acquavella*, 498 P.3d 911 (2021); *see also* UW Evans School Student Consulting Lab, *Defining Public Interest in Washington State: Analysis of Western State Approaches and Washington Stakeholder and Tribe Perspectives*, Publication 23-11-003, (Ecology, 2023), 11, https://apps.ecology.wa.gov/publications/documents/2311003.pdf; "Drought Response," Ecology, accessed November 3, 2025, https://ecology.wa.gov/water-shorelines/water-supply/water-availability/statewide-conditions/drought-response.

186. RCW 90.44.050.

187. WAC 173-150-040, -050.

A GCS project developer interested in the CRBG has two potentialities for improving their odds of securing a water right for a volume of groundwater that they can use year round, with minimal impairment to senior water rights holders. The first is to utilize degraded water (water high in TDS above the federal drinking water standard of 500 mg/L for potable water), such as brackish groundwater, for which there would be no to few competing water rights holders or water from an aquifer that is so deep no senior water right holder for that body of water exists.

Chapter 8: Hydrogeologic Setting evaluates the feasibility of obtaining such a water right.

The second possibility is to show that the carbonated water injection technique is entirely or nearly nonconsumptive by withdrawing from and injecting into the same aquifer while maintaining water quality.[188] This option would not reduce the volume needed for the water right permit but could significantly reduce the cost of any associated mitigation. Discussions with Ecology will be key to better understanding the feasibility of these options.

A transfer of groundwater rights is also a possibility for a pilot or commercial project. Water banks and large agricultural water rights holders may have water available within the CRBG. However, agricultural water rights holders frequently do not hold water rights for a large volume of water year-round, instead having the right to use a large volume during the irrigation season.

Development of a statewide GCS siting strategy, backed by solid groundwater quality data, could provide GCS project developers with increased confidence about both whether and where the conditions for a waiver of injection depths exist and whether and where saline or deep aquifers lie in the CRBG. Such a strategy also could encourage co-location of GCS sites with recycled sources of water for which no water right is needed, such as treated municipal effluent or industrial process or wastewater.

Technological Challenge

One significant technological barrier that both injection techniques face if deployed in Washington, a state with relatively low CO_2 emissions, is their preference for a steady supply of high-purity CO_2. A consistent supply helps maintain injection pressure and flow rates for the supercritical injection technique, and higher CO_2 concentrations reduce the overall water and energy requirements of the carbonated water injection technique.[189] While this constraint is unlikely to pose a challenge for a pilot-scale demonstration needing a small volume of CO_2, it could become a significant barrier at commercial scale, where target injection volumes reach at least 1 million MT CO_2 per well annually, unless a direct air capture (DAC) plant is sited nearby.[190]

188. At the time of drafting, Ecology's guidance document on consumptive and nonconsumptive water use, POL-1020, is under public review and comment. Changes to this policy could affect these conclusions.

189. Ying Teng et al., "Experimental Evaluation of Injection Pressure and Flow Rate Effects on Geological CO_2 Sequestration Using MRI," *Energy Procedia*, vol. 114 (July 2017): 4986–93, https://doi.org/10.1016/j.egypro.2017.03.1642; Snæbjörnsdóttir et al., "Carbon Dioxide Storage through Mineral Carbonation," 99.

190. Injection and Geologic Sequestration of Carbon Dioxide: Federal Role and Issues for Congress (2025), https://www.congress.gov/crs-product/R46192.

Figure 10. Photo of Mt. Adams (Pahto), WA. *Carbon Containment Lab.*

Financial Challenge

The regulatory, social, and technical constraints obstructing GCS projects in Washington amplify the financial barriers to successful project deployment. From preparing permit applications to regulatory site closure, a commercial-scale project storing 1 million MT CO_2 per year annually for 20 years in a conventional storage reservoir costs $400M to $1.08B (at $20–$54/ton CO_2).[191] A first-of-a-kind GCS project in basalt, untested and with higher initial risks, will cost more.[192] How much more is uncertain and, therefore, more difficult to finance.

First-of-a-kind GCS projects are essential for reducing the future cost of GCS by providing essential learnings that derisk nth-of-a-kind projects. These learnings lead to cost reductions by enabling the sunsetting of non-recurring engineering costs, achieving economies of scale, and fostering the maturation of the supply chain.[193]

However, current financing prospects present a challenging picture. Global economic turmoil has created a difficult outlook for new infrastructure, raising construction costs. The federal 45Q tax credit may be inadequate to drive significant deployment of carbon capture technologies, a critical input for GCS projects and a necessary factor for securing sufficient project financing.[194] The lack of a state protocol for issuing carbon credits to high-integrity CCS and CDR with GCS projects also inhibits adoption of carbon capture and removal and related technologies. Overcoming these barriers to deliver first-of-a-kind GCS projects requires blended finance structures coupled with state-level support, to absorb or lessen the projects' higher initial risks and potential liabilities.

Statutory Challenge: Dearth of State Laws on GCS

Lastly, other states have passed laws or taken other actions enabling GCS. Washington has not. Indeed, the Legislature has not yet enacted any laws governing pore space ownership, unitization, encroachment, and long-term monitoring and liability, nor does it have a law

191. Pett-Ridge et al., *Roads to Removal*, 4–13.

192. *Id*. at 4–9.

193. Eli Bashevkin et al., *Portfolio Insights: Carbon Capture in the Power Sector* (Office of Clean Energy Demonstrations, 2024), 9, https://www.energy.gov/sites/default/files/2024-04/OCED_Portfolio_Insights_CC_part_i_FINAL.pdf.

194. "Ensuring the Continued Success of the Carbon Management Industry Through a Robust 45Q Tax Credit," Carbon Capture Coalition, May 9, 2025, https://carboncapturecoalition.org/blog/ensuring-the-continued-success-of-the-carbon-management-industry-through-a-robust-45q-tax-credit.

explicitly encouraging use of state trust lands for GCS. Without this regulatory environment, the State is less attractive to GCS project developers deciding where to site and operate their projects.

The pore space into which CO_2 is injected and mineralizes is private property. A landowner owns all property below them, except when an estate is severed into surface and mineral estates.[195] In such a case, the vast majority of states have determined that the owner of the surface estate, not the owner of the mineral estate, owns the pore space, unless there is express language to the contrary in a conveyance or reservation of property.[196] (Still, the "surface owner does not possess full rights in the pore space until the mineral owner has extracted the minerals."[197]) Washington law, however, is silent on this matter. Though it is assumed that Washington will follow the majority, without a specific law clarifying pore space ownership, or clear direction from DNR, GCS project developers face uncertainty regarding the property owner from whom to purchase these rights.

Securing a contiguous block of pore space rights can be onerous, particularly when the subsurface area extends below numerous separately owned surface estates. Pore space unitization laws lower this obstacle for project developers by authorizing or compelling separately owned adjoining parcels to consolidate for development of the subsurface as a single storage unit.[198] Washington has unitization laws for oil and gas and geothermal production but not yet for GCS.[199]

There is a risk that a CO_2 injection plume will migrate beyond the area for which pore space rights have been acquired. This encroachment can rise to the level of trespass or nuisance, depending on a state's laws.[200] Washington has not yet determined whether an invasion of pore space alone triggers legal liability or whether interference with use and enjoyment of the pore space also is required. This lack of clarity creates a risk for project developers and could deter them from developing projects in-state.

Several states have laws transferring responsibility for post-closure monitoring and the long-term liability of CO_2 storage from a project developer to the State after regulatory closure.[201] This transfer of monitoring responsibility and liability has a dual benefit: It frees a GCS project developer so that they can move on and develop elsewhere, and it reassures the public continuously that the mineralized CO_2 is securely in place and presenting no risk to human or environmental health. Adopting such a law in Washington would better position the State to become a global GCS hub.

Finally, some states, like Alaska and Alabama, have passed laws explicitly making public

195. Hannah Wiseman, *Defining Pore Space Ownership and Related Issues: A Summary*, 1–2, https://celp.psu.edu/wp-content/uploads/2022/12/Definition-of-pore-space-and-related-issues_Summary-for-posting.pdf.

196. *Id*. (This rule is known as the "American Rule." At least Alaska follows the "English Rule," holding that the mineral estate owner owns the pore space rights.); William Gallin et al., "Is Your State Regulation Ready? A Review of Geologic Carbon Sequestration Regulations in the United States," 7, preprint, submitted September 2025.

197. Wiseman, *Defining Pore Space Ownership*, 1–2.

198. Madeleine Lewis, Issue Brief: Pore Space Unitization for Geologic Sequestration of Carbon Dioxide (University of Wyoming), 2–3, https://carboncaptureready.betterenergy.org/wp-content/uploads/2024/07/SER-Unitization-Analysis_FINAL.pdf.

199. *See* RCW 78.52.335 (oil and gas); RCW 79.14.100 (oil and gas); RCW 78.60.160 (geothermal).

200. Gallin, *Is Your State Regulation Ready?*, 11.

201. *Id*. at 10, 18.

lands available for GCS.[202] Others have encouraged GCS in other ways. Texas, for example, has already expressed its interest in developing a GCS economy by leasing lands for the benefit of its public schools.[203] Washington should consider following suit. **The State could eliminate several of the impediments to developing first-of-a-kind GCS projects in basalt, and motivate project developers to tackle the remainder, by forming a P3 and readying pre-selected state trust lands for lease.**

Conclusion

Without substantial political, financial, and policy support from the State designed to reduce these many barriers to GCS, project developers will continue to be deterred, and Washington could miss the chance to leverage its world-class basalt resources to establish itself as a global CCS hub, supporting both its own and the world's sequestration needs.

Section 3: Public-Private Partnership Planning, particularly **Chapter 12: Recommended Next Steps**, proposes near-term solutions for addressing the challenges set forth herein.

KEY TAKEAWAYS:

- Because GCS project developers interested in Washington have a relative paucity of publicly available subsurface data to inform their injection siting decisions, they must gather detailed site information themselves, increasing the time and expense of siting and project development. This scarcity of data, especially for the deeper parts of the CRBG that could host GCS projects, also means it is unconfirmed which formations could best support safe and permanent GCS. Lacking this information, no meaningful government-to-government consultation about a regional GCS siting strategy has occurred. The absence of such a strategy makes engagement with rightsholders and stakeholders more challenging for GCS project developers.

- The near- to medium-term permitting pathway for GCS in the CRBG is murky. Washington has primacy over Class V wells constructed and operated to test experimental technologies, including for GCS. Washington does not have primacy over Class VI wells—wells that are not experimental in nature and are used for long-term GCS.

202. AK HB 50 (2024); AL HB 327 (2024), Ala. Code § 9-17-165.

203. "Texas Land Commissioner Buckingham Secures Largest Carbon Sequestration Lease in the United States," Texas General Land Office, effective October 4, 2024, https://www.glo.texas.gov/about-glo/press-releases/texas-land-commissioner-buckingham-secures-largest-carbon-sequestration.

  - Ecology permitted the Wallula Basalt Pilot Project's well as a Class V well. It is expected that Ecology will also permit the first-of-a-kind small-scale limited duration pilot project using the carbonated water technique as a Class V well.

  - Whether the USEPA will conclude that the next several nth-of-a-kind early-stage GCS projects injecting into basalt at less than commercial-scale volumes qualify as pilot projects testing and refining experimental technologies—whether it permits these wells as Class V or VI wells—is unpredictable. If Washington gains primacy, this decision will belong to Ecology in consultation with USEPA. Ultimately, creation of a new UIC well class fit for the purpose of regulating CO_2 injections into basalt might be needed.

- The federal UIC Class VI regulations require that injections occur below the lowermost USDW unless an aquifer exemption is granted or a waiver is obtained. The federal aquifer exemption provision is not part of Washington's UIC program, so no aquifer exemption is permissible for a Class V experimental technology GCS well. No exemptions associated with Class VI wells are permissible in Washington either because only pre-existing aquifer exemptions associated with conversion of a Class II EOR well to a Class VI well are eligible, and there are no Class II EOR wells in Washington. The unavailability of an aquifer exemption for a Class VI well could deter project developers desiring a pathway to commercial-scale operations because, based on available data, it is suspected that the deeper CRBG aquifers have TDS values less than 10,000 mg/L TDS, and it is unknown whether the conditions for a waiver exist.

- CO_2 streams that are captured and injected into a Class VI well do not qualify as hazardous waste and are exempt from RCRA. CO_2 captured at a point source and injected into a Class V well as part of a pilot project, and CO_2 drawn from the atmosphere and injected into either a Class V or VI well, are presently not granted this explicit exemption; however, other regulations indicate that CO_2 does not qualify as hazardous waste, and no exemption is even needed. This ambiguity imposes an additional burden on both pilot-scale and more climate-friendly CDR+S projects, which will need to engage regulators to determine the correct regulatory pathway.

- The carbonated water injection technique presents a particular challenge: the need to obtain a water right permit for approximately 25 MT of water per ton of CO_2 sequestered. Because water availability is reduced due to climate-induced drought and water rights have been over-allocated across much of eastern Washington, obtaining a new water right permit to withdraw surface water in the area of the CRBG for the carbonated water injection technique is expected to be challenging at pilot-scale volumes and impossible at commercial-scale volumes. Obtaining a new permit to withdraw groundwater for GCS is expected to be challenging at either scale, if subsurface conditions allow.

    - A GCS project developer can improve their odds/lower their costs of securing a water right for a volume of groundwater that they can use year round by (1) utilizing either non-potable water, such as brackish groundwater, or water from an aquifer with TDS values higher than 500 mg/L that is so deep that no senior water right holder for that body of water exists, or (2) reducing the need for mitigation by showing that the carbonated water injection technique is entirely or nearly nonconsumptive. Development of a statewide GCS siting strategy could provide GCS project developers with increased confidence about whether and where saline or deep aquifers lie in the CRBG. It could also encourage co-location of GCS sites with recycled sources of water for which no water right is needed, such as treated municipal effluent or industrial process or wastewater.

- Serious gaps in regulatory oversight over CO_2 pipeline siting and safety exist. Recent cancellations of CO_2 pipeline projects indicate public confidence in any new or converted CO_2 pipeline is expected to be low, at least until the State creates a working group to identify potential CO_2 transportation corridors, expands EFSEC's and UTC's jurisdictions, and drafts regulations governing CO_2 pipeline safety for all three phases of CO_2.

- One significant technological barrier that both injection techniques face if deployed in Washington, a state with relatively low CO_2 emissions, is their preference for a steady supply of high-purity CO_2.

- The regulatory, social, and technical constraints obstructing GCS projects in Washington amplify the financial barriers to successful project deployment. From preparing permit applications to regulatory site closure, a commercial-scale project storing 1 million MT CO_2 per year for 20 years in a conventional storage reservoir costs \$400M to \$1.08B (at \$20–\$54/ton CO_2). A first-of-a-kind GCS project in basalt will likely cost more. The lack of a state protocol for issuing carbon credits under the CCA or CFS for high-integrity CCS and CDR+S projects keep these costs high.

- The Legislature should consider enticing GCS project developers to the State by enacting laws governing pore space ownership, unitization, encroachment, and long-term monitoring and liability, which would provide certainty and reassurance to the public as well. The Legislature also should follow the example of other states and pass a law or take another action, such as forming a P3, explicitly encouraging the lease of state trust lands for GCS.

II. Siting Assessment

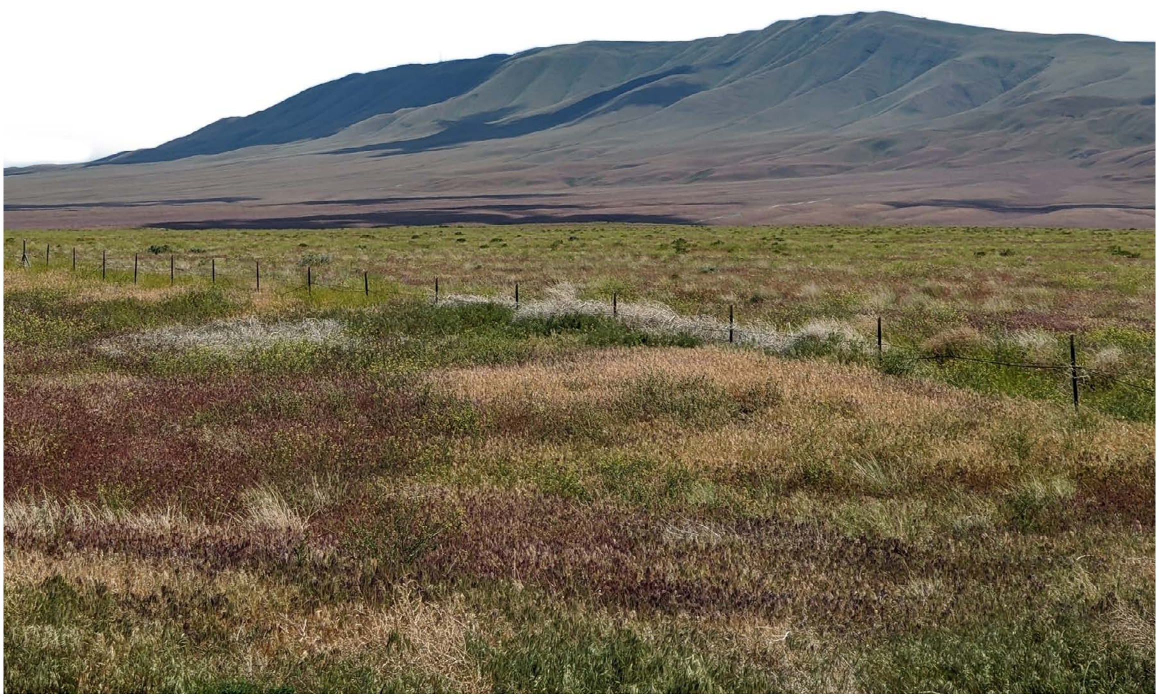

Figure 11. Photo of anticline, WA. *Carbon Containment Lab.*

5. Siting Criteria

Siting Criteria

In February 1889, the U.S. government passed the Enabling Act, inviting Washington to join the Union and granting Washington hundreds of thousands of acres of land to provide a source of revenue for public education.[204] "[T]he federal government intended to create a trust whereby the State accepted control of the granted lands with the express understanding that the lands were not its absolute property but, instead, were to be held and used" for public education.[205] **The Washington Constitution, which was ratified shortly afterwards, reiterates that "[a]ll the public lands granted to the [S]tate are held in trust for all the people[.]"[206]**

Today, DNR manages approximately three million acres of state trust agricultural, forest, aquatic, and range lands and commercial properties.[207] (See Figure 12.) DNR manages these state trust lands to produce non-tax revenue for public education, including from lease payments for agricultural production, energy production, mineral prospecting and mining, and from harvesting and selling biomass byproducts.[208]

As explained further in Section 3: Public-Private Partnership Planning, we suggest DNR also lease state trust lands for GCS and sell the underlying pore space rights, thereby increasing the revenue available for trust beneficiaries and helping to relieve a major hurdle inhibiting GCS deployment in-state: siting. **This use is in the best interest of the State and its citizens.[209]**

204. Enabling Act, ch. 180, § 10, 25 stat. 676, 679 (1889); *see also National Parks & Conservation Association v. Board of State Lands*, 869 P.2d 909, 917 (Utah 1993).

205. *Conservation NW v. Comm'r of Pub. Lands*, 199 Wn. 2d 813, 826, 514 P.3d 174 (2022).

206. WASH. CONST. art. XVI, § 1.

207. "Forest and Trust Lands," DNR, accessed November 7, 2025, https://dnr.wa.gov/forest-and-trust-lands; *see generally* RCW 79.02.

208. *Id*.; "Funding Schools and Services," DNR, accessed November 7, 2025, https://dnr.wa.gov/about-washington-dnr/funding-schools-and-ser2 vices.

209. RCW 79.10.100–.110.

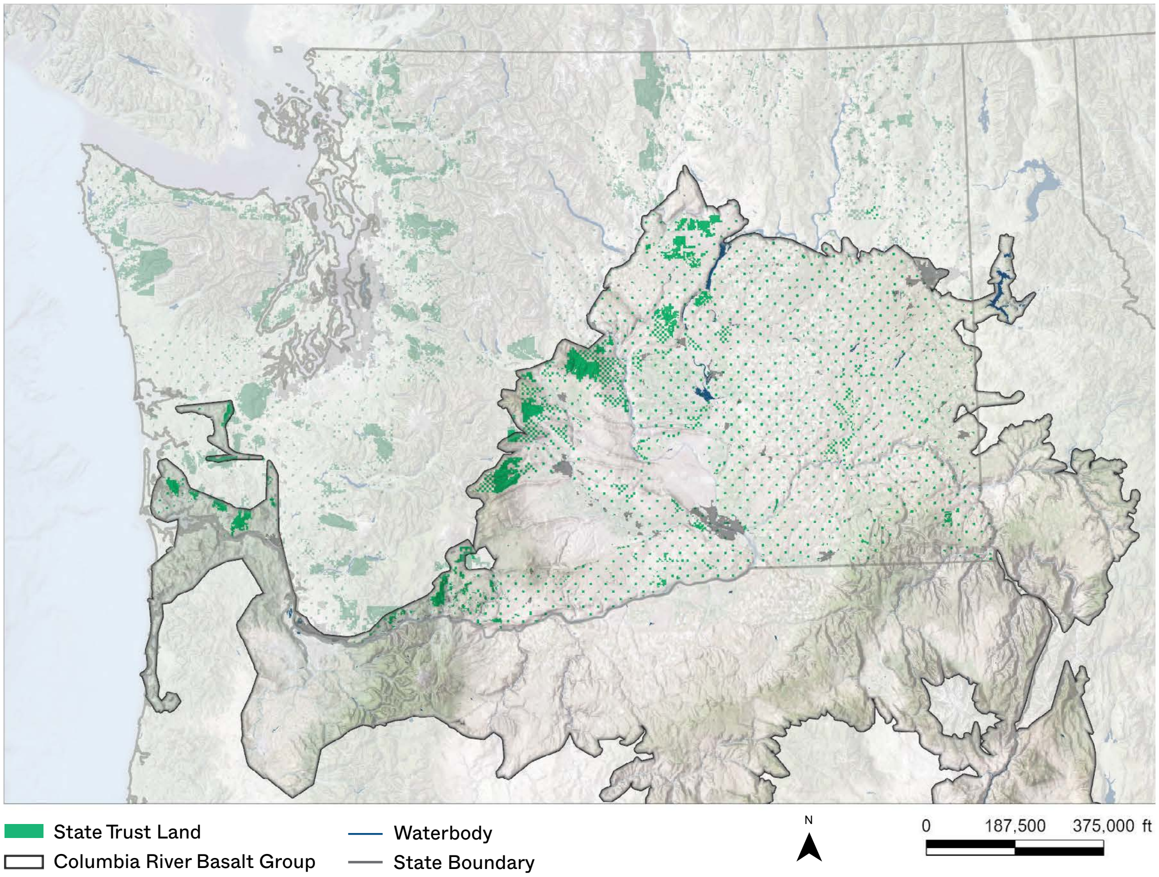

Figure 12. State trust lands managed by DNR. The CRBG underlies 1,420,800 acres of state trust lands, shown in darker green.[210]

The CRBG underlies 1,420,800 acres of state trust lands. (See Figure 12.) Deciding which are most suitable for GCS to reach net-zero emissions in-state requires identifying parcels that satisfy several conditions. Each parcel must:

- be sufficiently close to a source of carbon pollution needing sequestration—a point source utilizing carbon capture technology or a CDR facility—such that the cost and any emissions associated with transporting the CO_2 are not at odds with project goals;
- overlay geologic and hydrogeologic conditions deemed regulatorily safe and practically conducive for CO_2 injection and mineralization; and,
- if the carbonated water injection technique is used and an alternative water source is unavailable, offer an opportunity to obtain a water right permit for a sufficient volume of water.

210. "WA DNR Managed Land Parcels," Washington Spatial Data, last modified October 24, 2025, https://geo.wa.gov/datasets/wadnr::h wa-dnr-managed-land-parcels/explore.

Also, deployment should proceed at a parcel only if:

- Indian Tribes with reservations, ceded territories, and/or other Tribal interests in the region and the local community at large do not oppose deployment;

- adverse impacts to archeological, cultural, and historic resources are avoided or minimized and mitigated; and

- adverse environmental impacts are avoided or minimized and mitigated.

The following chapters of this section present, at a desktop level of assessment, three of the key criteria described above: (1) current and future sources of CO_2 that, whether through capture or removal, could require or be available for GCS; (2) Washington's geology and hydrogeology to identify state trust lands suitable for hosting GCS projects; and finally, (3) high-level conclusions from a cultural resources literature review, undertaken with the aim of informing a potential statewide GCS siting strategy.

Further assessments, Tribal consultation, and community engagement will be required to transform the initial findings described below into a statewide strategy for deployment.

6. Stocktake of Carbon Dioxide Pollution

RECAP FROM PRIOR CHAPTERS

- Washington has exhibited strong leadership and commitment to mitigating climate change through its statewide emissions reduction targets and corresponding climate legislation like the CCA, CETA, and CFS.
- Rising energy demand, infrastructure bottlenecks, and permitting delays are hindering the State's clean energy transition and causing increased reliance on fossil fuels, particularly natural gas.
- CCS, CDR+S, and GCS are all critical to maintaining grid reliability, decarbonizing industry, and achieving net-zero emissions by mid-century. State modeling estimates that at least 11.6 million MT CO_2e released annually will need offsetting via CDR+S to achieve net-zero emissions.

Stocktake of Carbon Dioxide Pollution

State of GHG Emissions

Washington's GHG emissions reductions are currently not on track to meet reduction targets. The January 2025 *Washington State Greenhouse Gas Emissions Inventory: 1990–2021* shows the State overshot its emission-reductions goals in 2021 by 5.6 million MT CO_2e.[211] That year, the State's consumption of fossil fuels emitted 73.5 million MT CO_2: 49.8 million MT CO_2 from petroleum, 20.2 million MT CO_2 from natural gas, and 3.5 million MT CO_2 from coal.[212] Three sectors of the economy recorded higher emissions than the State's 1990 baseline: electricity consumption, transportation, and fugitive fossil fuel emissions. Meanwhile, four sectors of the economy recorded lower emissions than the 1990 baseline: industrial processes, waste management, building emissions, and agriculture.[213] Of these seven sectors, (1) the electricity consumption, (2) industrial processes, (3) agriculture, and (4) fugitive fossil fuel sectors have a coming need for additional carbon management strategies to meet the State's reduction targets.[214] The State should consider encouraging development of a large enough portion of its basalt resources to safely and permanently store the CO_2 needed for these sectors to reach net zero.

- **Emissions related to electricity consumption** in 2021 stemmed from coal (8.8 million MT CO_2e) and natural gas electricity generation (4.7 million MT CO_2e), as well as electricity imported through bulk energy markets (5.2 million MT CO_2e).[215] While the State's lone coal power plant will retire in 2025, the State continues to rely heavily on its fifteen natural gas power plants to provide electricity for a high standard of living for its residents. In 2023, natural gas represented 12% of the State's aggregate fuel mix for electric utilities.[216]

- **Process and fugitive emissions in the industrial sector** in 2021 totaled 4.3 million MT CO_2e. The sector included CO_2 emissions from industrial processes related to cement (0.4 million MT CO_2e), iron and steel (0.3 million MT CO_2e), aluminum (0.2 million MT CO_2e), and ammonia production (0.1 million MT CO_2e).[217] The industrial sector as a whole was dominated by rising ozone-depleting substance substitute emissions (2.2 million MT CO_2e).[218] These non-CO_2 emissions are projected to increase through 2050 and require offsetting through CDR+S.[219]

211. Greenhouse Gas Inventory Unit, *Washington GHG Inventory*, 18.

212. Energy Information Administration, "Washington: State Profile and Energy Estimates," September 22, 2025, https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_co2/total/co2_tot_WA.html&sid=WA.

213. Greenhouse Gas Inventory Unit, *Washington GHG Inventory*, 19.

214. The remaining sectors are poor candidates for CCS and CDR+S because they have emissions profiles that are incompatible with conventional carbon capture technologies, robust alternative decarbonization pathways, or both. For instance, the transportation sector's emissions are mobile and diffuse, and a clear decarbonization strategy for the sector exists as laid out in the Draft CCAP, the CFS, and zero-emissions vehicle standards. Emissions from solid waste and wastewater management facilities have achievable decarbonization strategies (Measures 8.5.1–2 of the Draft CCAP) and robust electrification pathways have been identified for mitigating building emissions from the on-site combustion of fossil fuels in the residential and commercial sector (Strategy 3.2 of the Draft CCAP).

215. Greenhouse Gas Inventory Unit, "State Greenhouse Gas Inventory," 26.

216. Energy Policy Office, *Washington Electric Utility 2023 Fuel Mix Disclosure Report*, 7.

217. Greenhouse Gas Inventory Unit, *Washington GHG Inventory*, 19.

218. *Id*. at 39.

219. Evolved Energy Research and CETI, *CPRG Summer Quarterly Meeting: Emissions Modelling*, July 2025, 27.

- **Emissions in the agricultural sector** in 2021 totaled 6.6 million MT CO_2e and consisted largely of methane and nitrous oxide emissions from enteric fermentation (3.0 million MT CO_2e), manure management (1.6 million MT CO_2e), and agricultural soils (1.9 million MT CO_2e).[220] These non-CO_2 emissions are difficult to mitigate and are projected to persist at current levels through 2050.[221] The State expects that these emissions will be offset through CDR+S.[222]

- **Fugitive fossil fuel emissions** in 2021 totaled 1.4 million MT CO_2e and originated entirely within the natural gas industry. Consisting predominantly of methane leakages, these emissions will require offsetting by CDR+S while they persist.[223]

Emissions captured at natural gas power plants before retirement and hard-to-decarbonize industrial sources have the greatest need and suitability for CCS with GCS. Accordingly, they are assessed more thoroughly below. The contribution of CDR+S industries (i.e. DACCS and BECCS) to offset economy-wide residual non-CO_2 emissions and address legacy carbon pollution is also assessed.

Candidate CO_2 Sources for Carbon Capture with GCS in Washington

A sector's suitability and need for carbon capture with GCS depends on the following criteria. First, conventional CCS is only suitable for stationary point sources emitting CO_2 (typically the flue gas or process stream of a power plant or industrial facility).[224] Second, for the purposes of this report, annual CO_2 emissions must exceed 18,750 MT CO_2 for power plants and 12,500 MT CO_2 for industrial facilities—the minimum capture volume for 45Q tax credit eligibility—to be considered as a candidate CCS project site and to be included in calculations or analysis.[225] We use this criterion as a proxy indicating that project economics support retrofitting with carbon capture. Third, a sector has a demonstrated need for CCS if projections indicate its CO_2 emissions will persist in the future and no alternative feasible decarbonization pathways exist.

Chapter 12: Recommended Next Steps proposes that a more refined analysis of capture economics across the natural gas power plants and hard-to-decarbonize industrial facilities undertaken.

220. CETI, *Key Findings: Energy Pathways*, June 2023, 10, https://cdn.prod.website-files.com/64512dc345012a0e621f373f/64dd11b029a36f9097bd fdd6d_CETI_NZNW_Energy_Key-Findings_06-2023_Rev08-2023.pdf.

221. USEPA, "US State-Level non_CO_2 GHG Report Data Annex," accessed October 1, 2025, https://www.epa.gov/system/files/othe er-files/2022-03/state_level_nonco2_report_data_annex-030822.zip.

222. Evolved Energy Research and CETI, *Emissions Modelling*, 25, 27.

223. Greenhouse Gas Inventory Unit, *Washington GHG Inventory*, 43.

224. Sarah M. Forbes et al., *Guidelines for Carbon Dioxide Capture, Transport, and Storage* (World Resources Institute, 2008), 19, 23, https://files.wri.org/d8/s3fs-public/pdf/ccs_guidelines.pdf?_gl=1*1j5b7sh*_gcl_au*MzEyNTAzNTcwLjE3NjEzMzE3ODA.

225. "Credit for Carbon Oxide Sequestration," Internal Revenue Service, October 10, 2025, https://www.irs.gov/credits-deductions/credit-for-carbon-oxide-sequestration.

Electricity Generation

In 2023, Washington boasted the second-lowest state emissions rate for electricity production in terms of CO_2e, reflecting many years of investment and advanced planning.[226] Renewable resources and nonemitting electric generation sources like hydropower (49%), wind (11%), nuclear (4%), and solar (1%) feature heavily in the State's aggregate fuel mix for electric utilities.[227] Yet, Washington's electric utility fuel mix continues to comprise a significant share of electricity produced by fossil fuels, and from natural gas power plants specifically.

Figure 13. Photo of CRBG, Columbia River, and power lines, WA. *Carbon Containment Lab.*

Natural Gas Power Plants

The State's natural gas electric power plants are its last remaining fossil-fueled electricity sources. Of the 18 plants with annual CO_2 emissions that meet the 45Q emission threshold, 13 generate grid electrical power. Of these 13 plants, 11 are operated by one of four electric utility companies, one (Frederickson Power LP) is jointly operated by an independent power producer and an electric utility company, and one (Grays Harbor Energy Facility) is fully-owned by an independent power producer. In 2023, the four E-NGPP utilities reported the following shares of natural gas in their fuel mixes: Avista (41%), Clark County PUD #1 (32%),

226. USEPA, *eGRID Summary Tables 2023*, March 27, 2025, https://www.epa.gov/system/files/documents/2025-06/summary_tables_rev2.pdf.

227. Energy Policy Office, *Washington Electric Utility 2023 Fuel Mix Disclosure Report*, 7.

Puget Sound Energy (30%), and PacifiCorp (19%).[228] Frederickson Generating Plant is the only grid electrical power natural gas plant considered in this chapter that has a nameplate capacity and capacity factor consistent with serving only as a peaker plant.[229] The rest provide base or intermediate load to the state grid. Additionally, there are four industrial natural gas power plants in the state, and the University of Washington operates the sole commercial natural gas power plant that meets the 45Q emission threshold. (See Table 2 and Figure 14.)[230]

Evidence suggests that most grid electrical natural gas power plants operated by E-NGPP utilities will remain in operation—and CO_2 emissions will persist—at least until close to 2045, if not longer, pending State energy needs and potential changes to CETA. The IRPs of these utilities reflect varying levels of certainty surrounding future plans. Avista has scheduled expected retirement dates of 2029 for its Northeast plant and 2039 for Boulder Park and Kettle Falls.[231] Clark Public Utilities expects its River Road plant to transition from baseload power provider to peaking plant as wind and solar electricity generation increases. However, they still expect the plant to provide important flexibility to complement its portfolio of intermittent renewables through 2044.[232] Puget Sound Energy does not indicate retirement dates for its natural gas plants, instead expecting them to represent a consistent share of their electricity mix until 2030, before hydrogen blending gradually phases out natural gas consumption entirely by 2045.[233] PacifiCorp states that it lacks necessary information to evaluate alternative fueling options at its Chehalis Plant.[234]

Aside from ceasing operations, there is no decarbonization pathway for natural gas power plants besides CCS. CCS can reduce 95% of a natural gas plant's carbon emissions.[235] Retrofitting existing natural gas plants with carbon capture is estimated to cost $40–$70/MWh.[236]

228. *Id*.

229. The U.S. Government Accountability Office defines peaker plants as fossil-fueled power plants that have a capacity of 15 percent or less and a nameplate capacity greater than 10 MW. U.S. Government Accountability Office, *Electricity: Information on Peak Demand Power Plants*, May 21, 2024, 2, https://www.gao.gov/assets/gao-24-106145.pdf#:~:text=We%20generally%20define%20peakers%20as%20plants%20that,of%20greater%20than%2010%20megawatts%20of%20electricity.

230. John Stang, "Independent Power Producer Sees Risk from Washington Cap-and-Trade," RTO Insider, July 5, 2022, www.rtoinsider.com/30357-independent-power-producer-risk-wash-cap-trade.

231. Avista, *Draft 2025 Electric Integrated Resource Plan*, October 1, 2024, 33, https://www.myavista.com/-/media/myavista/content-documents/about-us/our-company/irp-documents/2025/2025-draft-electric-irp-complete.pdf. CO_2 emissions from natural gas power generation did not meet the 45Q emission threshold at Northeast or Kettle Falls, which is why they are not featured in Table 2 or Figure 14. See "Emissions by Plant and by Region," November 5, 2024, https://www.eia.gov/electricity/data/emissions/xls/emissions2023.xlsx.

232. Clark Public Utilities, *2024 Integrated Resource Plan*, August 2024, 69, https://www.clarkpublicutilities.com/wp-content/uploads/2024/08/CPU-2024-IRP_FINAL-Version-2-BPA-LF.pdf.

233. Puget Sound Energy, *2023 Electric Progress Report*, 2023, 3–5, 3–10, https://www.pse.com/-/media/PDFs/IRP/2023/electric/chapters/00_EPR23_AppendixBook_Final.pdf.

234. PacifiCorp, *2025 Integrated Resource Plan*, March 31, 2025, 194, https://www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/energy/integrated-resource-plan/2025-irp/2025_IRP_Vol_1.pdf.

235. *See, e.g.*, A.J. Simon et al., *Carbon Capture for Natural Gas-Fired Power Generation*, 7; "Just Catch: Standardized, Modular Carbon Capture Plant," SLB Capturi; "How It Works," ION Clean Energy.

236. Daniel Woldorff, "Hyperscalers Are Getting More Interested in Gas-plus-CCS," Latitude Media, May 2, 2025, https://www.latitudemedia.com/news/hyperscalers-are-getting-more-interested-in-gas-plus-ccs.

Table 2. Washigton's 45Q-Eligible Natural Gas Power Plants

ID	Facility	Sector	Road Distance from CRBG (miles)	Nameplate Capacity (MW)	Capacity Factor (%)	CO_2 Emissions (MT)
E-01	University of Washington - University of Washington Power Plant	Commercial Electrical Power	92	3.0	5	74,611
E-02	Avista Corp - Boulder Park	Grid Electrical Power	6	24.6	30	31,152
E-03	Capital Power Corp, Puget Sound Energy Inc - Frederickson Power LP	Grid Electrical Power	53	318.3	65	692,279
E-04	Clark Public Utilities - River Road Gen Plant	Grid Electrical Power	0	248.0	84	707,120
E-05	Invenergy - Grays Harbor Energy Facility	Grid Electrical Power	18	714.9	58	1,458,933
E-06	PacifiCorp - Chehalis Generating Facility	Grid Electrical Power	7	593.3	43	891,480
E-07	Puget Sound Energy Inc - Encogen	Grid Electrical Power	146	176.4	58	436,766
E-08	Puget Sound Energy Inc - Ferndale Generating Station	Grid Electrical Power	178	285.5	61	670,847
E-09	Puget Sound Energy Inc - Frederickson	Grid Electrical Power	53	177.8	10	116,475
E-10	Puget Sound Energy Inc - Fredonia	Grid Electrical Power	146	376.0	29	594,762
E-11	Puget Sound Energy Inc - Goldendale Generating Station	Grid Electrical Power	0	302.8	82	707,900
E-12	Puget Sound Energy Inc - Mint Farm Generating Station	Grid Electrical Power	0	319.0	71	768,816
E-13	Puget Sound Energy Inc - Sumas Power Plant	Grid Electrical Power	185	125.5	76	389,051
E-14	Puget Sound Energy Inc - Whitehorn	Grid Electrical Power	182	169.2	30	313,318
E-15	HF Sinclair Corporation - HF Sinclair Puget Sound Refining	Industrial Electrical Power	151	139.8	58	445,662
E-16	Longview Fibre Co - Longview	Industrial Electrical Power	0	45.0	8	162,695
E-17	Nippon Dynawave Packaging Co. - Nippon Dynawave Packaging Longview WA	Industrial Electrical Power	0	31.0	23	190,527
E-18	Port Townsend Paper Co - Port Townsend Paper	Industrial Electrical Power	116	7.5	2	21,392
					Total	**8,673,786**

CO_2 emissions and electricity generation data shown regard only a facility's consumption of natural gas. Low capacity factors among industrial electrical power plants could be a result of their reliance on other primary fuel sources. Road distance is measured to the nearest boundary of the CRBG. Facilities are sorted by sector and then alphabetized. Facilities are displayed by their ID on Figure 14.[237]

237. Energy Information Administration, "Emissions by Plant and by Region: Final Annual Data for 2023," November 5, 2024, https://www.eia.gov/electricity/data/emissions/xls/emissions2023.xlsx.

The deployment of carbon capture systems at natural gas power plants is at an early commercial stage. Net Zero Teesside Power in the United Kingdom, which aims to be the world's first natural gas-fired power station with CCS, is expected to produce 742 MW of electricity and to capture 2 million MT CO_2 per year beginning in 2028.[238] The Baytown Carbon Capture and Storage Project in Texas is expected to be the first full-scale implementation of CCS at a natural gas power plant in the U.S. and expects to capture up to 2 million MT CO_2 per year when it starts up, although no date has been specified.[239] In Washington, the Grays Harbor CO_2 Capture and Storage Hub Project won federal funding to explore the potential of storing 50 million MT CO_2 within a 30-year timeframe in a geologic storage complex in Grays Harbor County. This feasibility study will include an analysis of potential sources.[240] Lastly, in October 2025, Google announced an offtake agreement with the Broadwing Energy Project—a 400 MW natural gas power plant fitted with capture technology slated to begin capturing CO_2 in the early 2030s—to help fuel its data centers in the Midwest.[241] This landmark offtake agreement underscores that major technology companies, encountering delays in renewable resource deployment, are preparing to supplement their clean energy portfolios with investments in low-emission, advanced fossil-fuel systems to secure clean firm power.[242]

Waste-to-Energy

Washington's only waste-to-energy power plant is the 22 MW municipal solid waste incinerator plant operated by the City of Spokane's Solid Waste Disposal Department.[243] The plant emitted 124,047 MT CO_2 in 2023.[244] Reportedly driven by the costs of compliance with the CCA, Spokane commissioned Carbon Quest, a Spokane-based carbon capture technology company, to complete a feasibility study of retrofitting the waste-to-energy plant with carbon capture with GCS.[245] The volume of carbon capture that would occur at this site has not yet been publicly shared.

> "All pathways to stabilize global warming will require carbon sequestration and removal to offset emissions from sectors of the economy that are difficult to decarbonize." - Ecology[246]

238. "Greenlight for Net Zero Teesside Power," East Coast Cluster, accessed October 6, 2025, https://eastcoastcluster.co.uk/press-release/greena light-for-net-zero-teesside-power.

239. Office of Clean Energy Demonstrations, *Carbon Capture Demonstration Projects Program - Baytown Carbon Capture and Storage Project*, accessed October 26, 2025, https://www.energy.gov/sites/default/files/2024-07/Baytown_CCS_Factsheet_0.pdf.

240. "Projeo Corporation Selected by USDOE for CarbonSAFE."

241. Laila Kearney, "Google Backs US Gas Power Plant with Carbon Capture for Midwest Data Centers," *Reuters*, October 23, 2025, https://www.reuters.com/sustainability/boards-policy-regulation/google-backs-us-gas-power-plant-with-carbon-capture-midwest-data-centers-2025-10-23.

242. Vasil Velev, "Google Bets On Carbon Capture Power To Fuel The AI Boom," *Carbon Herald*, October 23, 2025, https://carbonherald.com/google-carbon-capture-power-fuel-ai-boom.

243. Hazardous Waste and Toxics Reduction Program and Solid Waste Management Program, *The State Solid and Hazardous Waste Plan* (Olympia, Washington: Ecology, December 2021), 44, https://apps.ecology.wa.gov/publications/documents/2104050.pdf; *see also* Energy Information Administration, "Emissions by Plant and by Region: Final Annual Data for 2023."

244. Energy Information Administration, "Emissions by Plant and by Region: Final Data for 2023."

245. Clouser, "CCA Compliance Could Cost Spokane over $210M to Renovate Waste-to-Energy Plant."

246. Greenhouse Gas Inventory Unit, 2025 Summary Report on the Science of Human Caused Climate Change, 31.

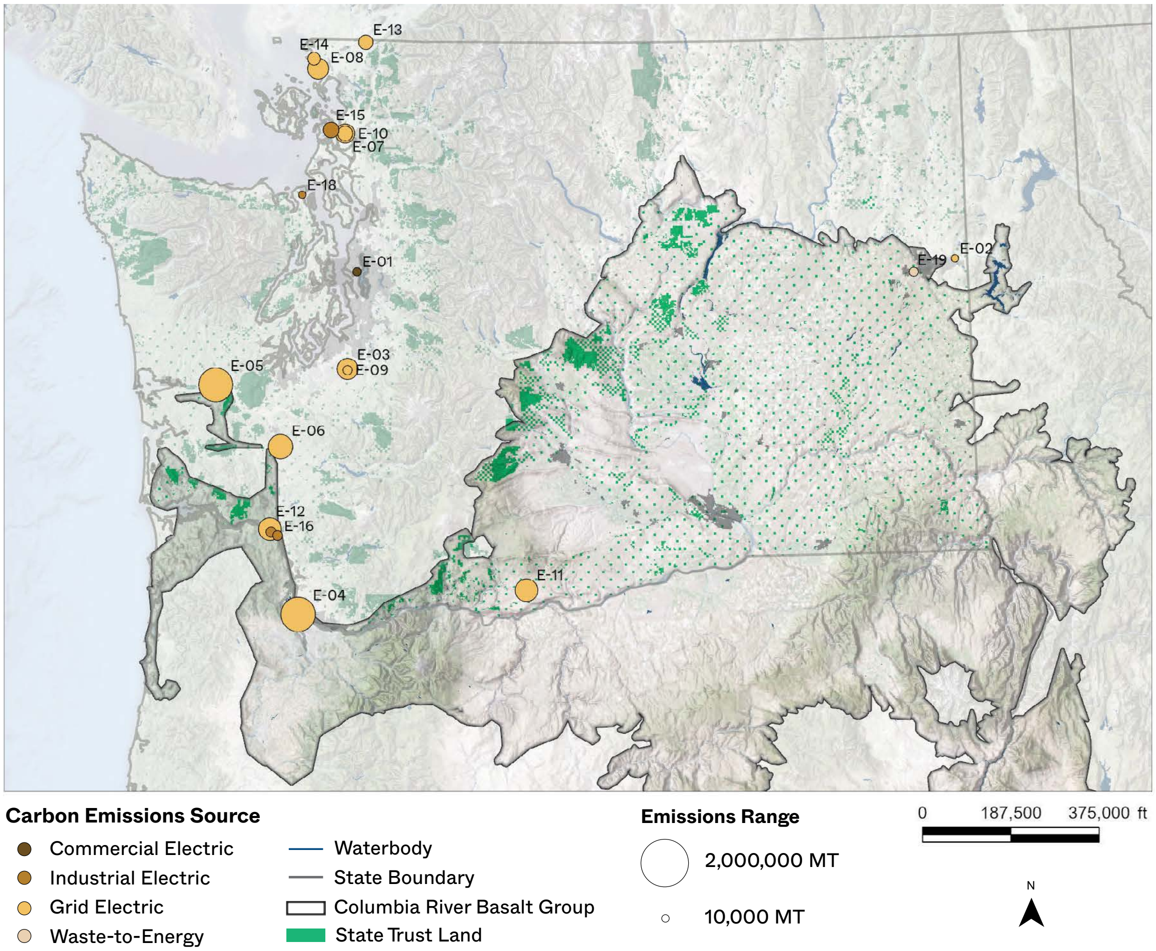

Figure 14. Map displays emissions volumes of 45Q-eligible natural gas and waste-to-energy power plants and their locations in relation to the CRBG. Volume of CO_2 emissions and road distance of the natural gas power plants are provided at Table 2, page 63. All data is from 2023.[247]

Industrial Sector

In 2021, on-site emissions from the industrial sector (comprising on-site fossil fuel combustion, industrial processes, and fugitive emissions), totalled 17.4 million MT CO_2e.[248] The State's forty EITEs make up the majority of the largest industrial sector emitters. The large number of no-cost allowances issued to EITEs indicates that industrial emissions will remain high at least through 2034 and will represent a growing share of economy-wide emissions. Policy uncertainty exists around the volume of no-cost allowances that will be issued for EITEs beyond 2034.[249] The five EITE sectors in Washington with the greatest potential suitability and need for CCS deployment are petroleum refineries, pulp and paper, cement, chemicals and hydrogen, and metals manufacturing. (See Table 3 and Figure 15.)

247. Energy Information Administration, "Emissions by Plant and by Region: Final Annual Data for 2023."

248. Greenhouse Gas Inventory Unit, *Washington GHG Inventory*, 40.

249. Drew Veysey et al., *Opportunities for Industrial Modernization in Washingto*n (RMI, 2025), 5, https://rmi.org/insight/opportunities-for-indust
trial-modernization-in-washington.

Petroleum Refineries

In 2023, Washington's five petroleum refineries reported emissions totaling 6.3 million MT CO_2. Total reported emissions across the sector have grown slightly, increasing by 3% between 2018 and 2023.[250] This increase, coupled with the fact that no-cost allowances are offered to keep EITEs in-state, suggests emissions can be expected to persist at a high volume between now and mid-century. Point source emissions from fluid catalytic cracking and steam methane reforming at petroleum refineries represent 22% and 9% of total emissions from U.S. refineries, respectively. Carbon capture is the best reduction method for such unavoidable process emissions.[251] The application of carbon capture is at the commercial stage for steam methane reformers and the early commercial stage for fluid catalytic crackers.[252] Carbon capture systems may also be needed to mitigate stationary combustion emissions (responsible for 63% of total emissions from U.S. refineries), depending on how broadly and rapidly fuel switching and electrification measures are adopted.[253]

Pulp and Paper Facilities

Pulp and paper facilities rely on a mix of bioenergy and fossil fuels to fire steam boilers and lime kilns. They produce biogenic emissions, which are considered carbon neutral and beyond the scope of the CCA, as well as nonbiogenic CO_2 emissions (i.e. not originating from living organisms). Nonbiogenic emissions originate from natural gas auxiliary and power boilers and lime kiln firing.[254]

Washington's pulp and paper sector is the second-most emitting EITE sector and the highest emitting manufacturing sector.[255] The sector reported 951,198 MT of nonbiogenic CO_2 emissions in 2023, representing 20% of its total (biogenic and nonbiogenic) emissions.[256] The five kraft pulp and paper mills operating at the time were responsible for 84% of these emissions (801,286 MT CO_2); four are still fully operational today.[257] Three other pulp and paper facilities also reported CO_2 emissions above 45Q's qualifying threshold for industrial

250. Ecology, "GHG Reporting Program Publication," Data.Wa.Gov, February 6, 2025, https://data.wa.gov/Natural-Resources-Environment/GHG-Reporting-Program-Publication/idhm-59de/about_data.

251. Zachary Byrum et al., *Technological Pathways for Decarbonizing Petroleum Refining* (World Resources Institute, 2021),4, 7, https://www.wri.org/research/technological-pathways-decarbonizing-petroleum-refining.

252. The carbon capture system being installed onto the fluid catalytic cracking process at the Phillips 66 Humber Refinery in the UK will be the first of its kind when it begins operations in 2027. Humber Zero News Team, "Phillips 66 Ltd Advances Carbon Capture Project in a Deal with Worley Using Shell's Cansolv CO_2 Capture Technology," Humber Zero, February 19, 2024, https://humberzero.co.uk/blog/phillips-66-ltd-ad0vances-carbon-capture-project-in-a-deal-with-worley-using-shells-cansolv-CO2-capture-technology. Since 2013, Air Products has captured approximately 1 million MT CO_2 per year from two SMR units at its Port Arthur Hydrogen Production facility. "Carbon Capture," Air Products, accessed October 5, 2025, https://www.airproducts.com/company/innovation/carbon-capture.

253. Byrum et al., *Decarbonizing Petroleum Refineries*, 5.

254. Veysey et al., *Opportunities for Industrial Modernization in Washington*, 51.

255. *Id*.

256. Ecology, "GHG Reporting Program."

257. The WestRock CP, LLC - Tacoma kraft mill ceased its operations in September 2023. *See* "WestRock Announces Plans to Close Tacoma, Wash., Paper Mill," WestRock, August 1, 2023, https://ir.westrock.com/press-releases/press-release-details/2023/WestRock-Announces-Plans-to-Close-Tacoma-Wash.-Paper-Mill/default.aspx. Also, although the February 2025 GHG Reporting Program Publication data lists the Georgia-Pacific Consumer Operations LLC - Camas facility as a kraft mill, the mill closed in 2018. The facility continues to make paper from purchased pulp. *See* Kelly Moyer, "Camas Seeks High Mill Cleanup Level," *Camas-Washougal Post-Record*, February 28, 2025, https://origin.camas-spostrecord.com/news/2025/feb/28/camas-seeks-high-mill-cleanup-level; *see also* "Georgia Pacific, Camas," Ecology, accessed October 30, 2025, https://ecology.wa.gov/regulations-permits/permits-certifications/industrial-facilities-permits/georgia-pacific-camas.

facilities.[258] The sector is projected to experience flat to modest growth in product output through 2034 (<1% per year), suggesting that these fossil fuel emissions will persist.[259]

Overall, steam generation represents four fifths of the sector's energy use and makes the sector difficult to electrify.[260] Capturing flue-gas CO_2 from recovery boilers and kilns will be needed to reduce the sector's emissions.[261]

While carbon capture technology has not yet been installed at any pulp and paper facility in Washington, the State is encouraging its use, as discussed more thoroughly in the BECCS section below, and at least one company, International Paper, is fitting its pulp and paper facility in Vicksburg, Mississippi with a carbon capture system. The Mississippi plant aims to capture 120,000 MT CO_2 per year by 2029, 55% of which will be nonbiogenic.[262]

Cement

The State's only cement manufacturing facility is the Ash Grove Cement Company plant in Seattle, which reported CO_2 emissions of 366,730 MT in 2023.[263] Ash Grove Cement Company has carbon capture projects under development at its Mississauga, Ontario, and Foreman, Arkansas, plants.[264] Process emissions from limestone calcination are estimated to account for two thirds of emissions.[265] These process emissions and emissions from fossil fuel combustion used to meet high thermal energy demands are challenging to decarbonize through conventional measures like electrification or energy and material efficiency gains, strongly suggesting that CCS will be an essential component of the sector's decarbonization strategy.[266]

CCS is not just needed but also feasible. Internationally, carbon capture systems are already deployed at cement manufacturing plants and are approaching the million-metric-ton scale.[267]

258. *Id*.

259. Veysey et al., *Opportunities for Industrial Modernization in Washington*, 17.

260. *Id*. at 16.

261. *Id*. at 17.

262. Office of Clean Energy Demonstrations, *Carbon Capture Pilot at Vicksburg Containerboard Meeting: Community Briefing*, February 28, 2024, 16, https://www.energy.gov/sites/default/files/2024-03/2024%20OCED%20Carbon%20Capture%20Pilot%20at%20Vicksburg%20Containerboard%20Briefing.pdf.

263. Ecology, "GHG Reporting Program."

264. Ash Grove Foreman Plant Awarded DOE CO_2 Capture and Storage Cooperative Agreement," Ash Grove, accessed September 26, 2025, https://www.ashgrove.com/newsroom/fkjqps9dgr3cd4ux2nl14797qrh7qz-tntec; "Carbon Upcycling and Ash Grove Break Ground on Canadian First-of-Its-Kind Carbon Capture and Utilization Facility," Carbon Upcycling, July 29, 2025, https://carbonupcycling.com/2025/07/29/carbon-upcycling-and-ash-grove-break-ground-on-canadian-first-of-its-kind-carbon-capture-and-utilization-facility.

265. Stockholm Environment Institute and CETI, *Washington State Industrial Emissions Analysis—Cement Case Study* (Commerce, 2021), 4, https://www.cleanenergytransition.org/files/washington-state-industrial-emissions-analysis-green-cement-case-study-july-30-2021-draft.

266. *Id*.; MPA UK Concrete, *UK Concrete and Cement Industry Roadmap to Net Zero* (MPA UK Concrete, 2020), 9, https://thisisukconcrete.co.uk/TIC/media/root/Perspectives/MPA-UKC-Roadmap-to-Beyond-Net-Zero_October-2020.pdf.

267. Heidelberg Materials have installed 400,000 MT CO_2/year carbon capture capacity at their cement plant in Brevik, Norway. *See* "World Premiere: CCS Cement Facility Opens in Norway," Heidelberg Materials, accessed October 2, 2025, https://www.heidelbergmaterials.com/en/pr-2025-06-18. They are also fitting their cement manufacturing plant in Edmonton, Alberta with 1 million MT CO_2 per year of carbon capture capacity, which will make it the first full-sized zero carbon cement plant in the world. *See* Todd Bush, "Alberta Set to Build World's First Full-Sized Zero Carbon Cement Plant," Decarbonfuse, March 17, 2025, https://decarbonfuse.com/posts/alberta-set-to-build-world-s-first-full-sized-zero-carbon-cement-plant.

Chemicals and Hydrogen

CO_2 emissions from chemical and hydrogen manufacturing facilities stem from their combustion of fossil fuels to meet their high thermal energy needs and from process emissions resulting from the sector's reliance on fossil fuels as feedstocks for most of its products.[268] In 2023, chemical manufacturing plants in Washington reported emissions totaling 135,490 MT CO_2.[269] The two facilities that reported the greatest CO_2 emissions—the Lanxess food preservative manufacturing facility in Kalama (60,120 MT) and the Solvay Chemicals "grey" hydrogen facility, which utilizes natural gas without carbon capture, in Longview (50,068 MT)—accounted for 81% of the sector's overall emissions.[270]

It is anticipated that emissions from chemical manufacturing plants will persist and emissions from hydrogen production may grow between now and mid-century. As Washington transitions to net zero, its hydrogen production and use is expected to grow. Hydrogen will provide fuel pathways with low- or no-CO_2 emissions to hard-to-decarbonize industrial sectors and to the transportation sector.[271] To meet this demand, Washington must install 0.8 gigawatts (GW) of electrolysis capacity and produce 200,000 MT of hydrogen by 2030, and it must install 4.5 GW of electrolysis capacity and produce 700,000 MT of hydrogen by 2050, all from a near-zero baseline.[272] The Pacific Northwest Hydrogen Hub includes six "green" (zero emission) hydrogen manufacturing facilities based in Washington, but, as of October 1, 2025, the federal government has revoked the Hub's federal funding.[273] Washington therefore might need to produce "blue" hydrogen (hydrogen generated from steam methane reforming from natural gas where the CO_2 emissions are captured) temporarily to meet anticipated demand for clean hydrogen. As mentioned previously, carbon capture systems are already deployed on steam methane reformers at the commercial scale.

Metal Manufacturing and Processing

In 2023, metal manufacturing and processing plants in Washington reported emissions totaling 232,568 MT CO_2. Two plants, the Kaiser aluminum rolling mill in Trentwood and the Nucor Electric Arc Furnace steel plant in Seattle, are responsible for a majority of these, reporting 124,706 and 82,355 MT CO_2, respectively.[274] The aluminum and steel industries are commonly understood to be difficult to decarbonize; however, it may be possible for these industries to meet their thermal energy requirements by transitioning to bioenergy or hydrogen.[275] Given this potential alternative decarbonization solution, although CCS ultimately might be necessary, we have excluded this sector's emissions from our estimations of the volume of CO_2 that the State should be prepared to sequester.

268. Stockholm Environment Institute and CETI, *Washington State Industrial Emissions Analysis* (Commerce, 2021), 17, https://cdn.prod.website-files.com/5d8aa5c4ff027473b00c1516/61ead8f94117717fd74a249b_Washington%20State%20Industrial%20Emissions%20Analysis%20July%2030%2C%202021%20Final.pdf.

269. Ecology, "GHG Reporting Program."

270. *Id*.

271. Commerce, *Green Electrolytic Hydrogen and Renewable Fuels: Recommendations for Deployment in Washington* (Commerce, 2024), 4, https://deptof2commerce.app.box.com/s/widfnmxbo8ijt3uozpoq91jzapu4dhae.

272. *Id*. at 6–7.

273. "Pacific Northwest Hydrogen Hub (PNWH2)," USDOE, accessed October 3, 2025, https://www.energy.gov/oced/pacific-northwest-hydrogen-hub-pnwh2; "White House Strips Funding Promised to Pacific Northwest Hydrogen Hub," Maria Cantwell United States Senator for Washington, October 2, 2025, accessed October 26, 2025, https://www.cantwell.senate.gov/news/press-releases/white-house-strips-funding-promised-to-pacific-northwest-hydrogen-hub.

274. Ecology, "GHG Reporting Program."

275. Veysey et al., *Opportunities for Industrial Modernization in Washington*, 23; "Making Sustainability Possible," Kaiser Aluminum, accessed October 6, 2025, https://www.kaiseraluminum.com/sustainability.

Table 3. Nonbiogenic CO_2 Emissions from 45Q-Eligible Petroleum Refining, Pulp and Paper, Cement, and Chemicals and Hydrogen Facilities

ID	Facility	Sector	Road Distance from CRBG (miles)	CO_2 Emissions (MT)
I-01	Ash Grove Cement Company - Seattle	Cement Production	87	366,730
I-02	Ascensus Specialties LLC - Elma	Chemicals and Hydrogen	21	13,845
I-03	LANXESS Corporation - Kalama	Chemicals and Hydrogen	11	60,058
I-04	Solvay Chemicals, Inc. - Longview	Chemicals and Hydrogen	0	50,068
I-05	Nippon Dynawave - Longview	Kraft Mills	0	369,145
I-06	Packaging Corporation of America - Wallula	Kraft Mills	0	83,592
I-07	Port Townsend Paper Corporation - Port Townsend	Kraft Mills	117	57,063
I-08	WestRock LLC - Longview	Kraft Mills	0	176,257
I-09	Inland Empire Paper Company - Spokane	Newsprint Mills	1	16,269
I-10	North Pacific Paper Company, LLC - Longview	Newsprint Mills	0	36,357
I-11	Greif, Tacoma Mill - Tacoma	Paperboard Mills	59	13,047
I-12	bp Cherry Point Refinery - Blaine	Petroleum Refineries	183	2,052,443
I-13	HF Sinclair Puget Sound Refinery LLC - Anacortes	Petroleum Refineries	151	1,890,710
I-14	Marathon Anacortes Refinery - Anacortes	Petroleum Refineries	153	1,196,960
I-15	Phillips 66 Ferndale Refinery - Ferndale	Petroleum Refineries	179	898,414
I-16	U.S. Oil & Refining Co. - Tacoma	Petroleum Refineries	62	146,643
I-17	Georgia-Pacific Consumer Operations LLC - Camas	Tissue and Towel Mill	0	48,436
			Total	**7,476,037**

Given that biogenic CO_2 emissions fall beyond the scope of the CCA, our analysis herein of CCS as an emissions-mitigation tool excludes these emissions and only applies to the above facilities' nonbiogenic CO_2 emissions. Road distance is measured to the nearest boundary of the CRBG. Facilities are sorted by sector and then alphabetized. Facilities are displayed by their ID on Figure 15, below. All data is from 2023.[276]

276. Ecology, "GHG Reporting Program."

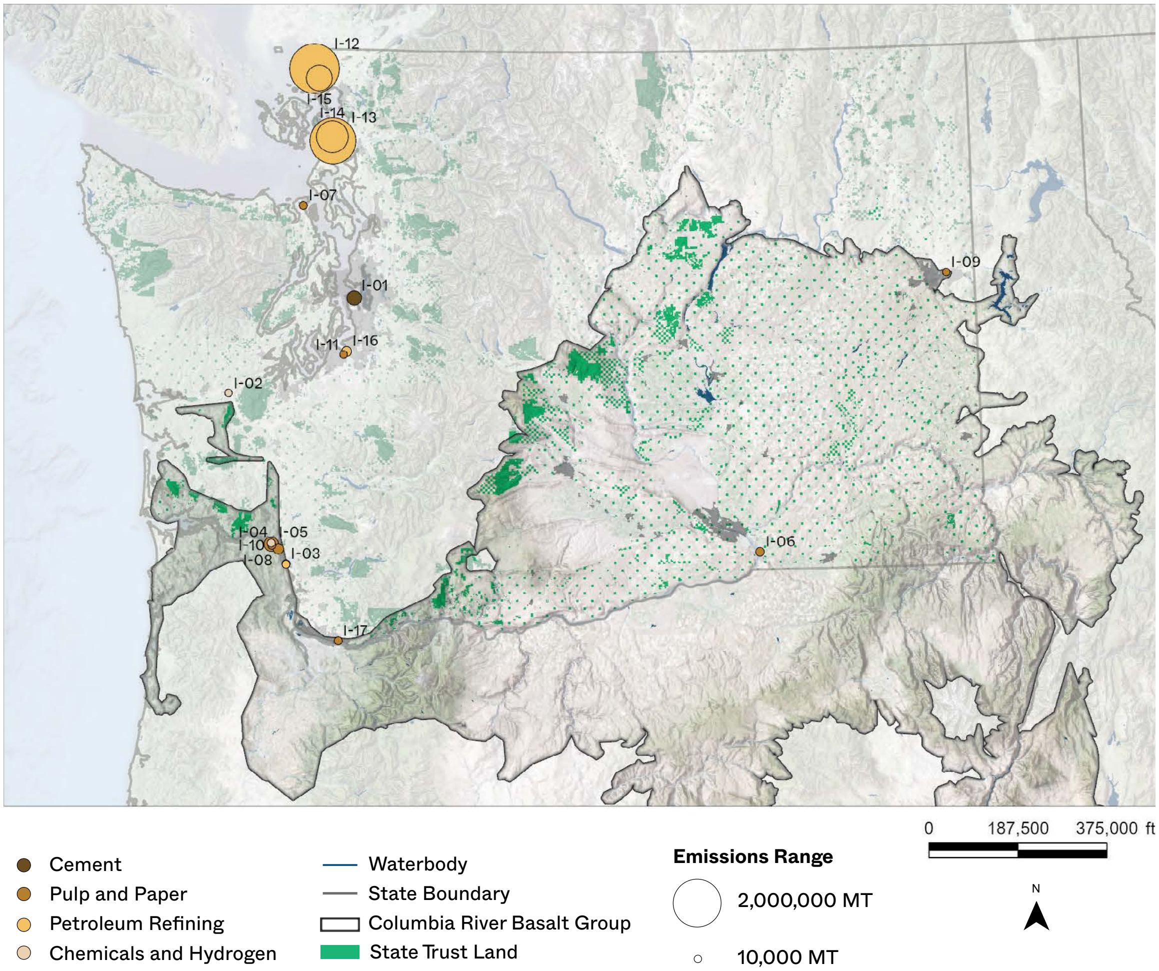

Figure 15. Map displays emissions volumes of 45Q-eligible petroleum refining, pulp and paper, cement, and chemicals and hydrogen facilities and their locations in relation to the CRBG. Volume of CO_2 emissions and road distance are provided in Table 3, page 69. All data is from 2023.[277]

Candidate CO_2 Sources for Carbon Removal with GCS

GCS also is needed to support deployment of emerging CDR technologies capable of both offsetting the significant residual emissions that the State expects to persist in the economy and, ultimately, to go beyond net zero and reduce legacy pollution that continues to warm the planet.[278] In its Draft CCAP, the State has identified two CDR+S opportunities that could utilize in-state GCS: DACCS and BECCS. [279] (See Table 4 and Figure 17.)

277. Ecology, "GHG Reporting Program."

278. Washington Climate Partnership, *Draft CCAP*, 230.

279. *Id*. at 107, 194. BECCS pathways involve the production of bioenergy (electricity, liquid fuel, biogas, or hydrogen) from renewable biomass feedstocks with integrated CCS. BECCS is a subsector of the broader biomass carbon removal and storage (BiCRS) field, which encompasses long-term storage options for carbon that plants have removed from the atmosphere via photosynthesis. *See* Pett-Ridge et al., *Roads to Removal*, 6-4. DAC is an engineered, two-stage carbon removal pathway wherein a reactive material selectively captures atmospheric CO_2 before being regenerated through an energy input and releasing a pure stream of CO_2. The reactive material used by DAC systems determines the energy requirements of the process. Adsorbent-based DAC systems can meet their energy requirements through renewables and low-grade or waste heat, while solvent-based DAC systems typically rely on natural gas to meet their thermal energy requirements. *See id*. at 7–4, 7–6.

Direct Air Carbon Capture and Storage

Eastern Washington offers both the clean energy and geologic storage potential necessary to support DACCS deployment.[280] The world's largest currently operating DAC facility is Climeworks's geothermal, adsorbent-based Mammoth plant in Iceland. It has a nameplate capture capacity of 36,000 MT CO_2 per year.[281] Occidental will launch operations at Stratos—a natural gas-powered and sorbent-based DAC facility with a nameplate capacity of 500,000 MT CO_2 per year—in Texas by the end of 2025.[282] 280 Earth's DAC facility in The Dalles, OR, began operations in 2024, capturing 500 MT CO_2 per year.[283] It is expected to capture over 20,000 MT CO_2 per year at full buildout.[284]

DACCS's demand for clean firm energy presents a limiting constraint that adds significant uncertainty to its deployment in-state.[285] Irrespective of approach (adsorbent or sorbent), DAC systems have a current energy demand of 8 GJ per MT CO_2 removed from ambient air, translating to a firm energy demand of 250 MW to grow to the million-tonne-per-year scale.[286] Dedicating renewable electricity capacity to DACCS operations could prove contentious given the pressing need to decarbonize the State's grid to meet the emissions reductions targets set out in CETA and to continue meeting residents' energy needs.[287] It is possible that the Legislature will determine that the State's fleet of natural gas plants—if retrofitted with carbon capture systems and not ready for retirement—could power DACCS operations in the future, after all other electricity demand in the State has been met.

Bioenergy with Carbon Capture and Storage

BECCS relies on the capture and storage of biogenic CO_2 emissions from biomass conversion facilities to generate negative emissions.[288] The State's extensive commercial forestry and wildfire risk mitigation activities endow it with the ingredients for success: abundant feedstock, well-established supply chains, a skilled workforce, and supportive infrastructure.[289]

Presently, the Kettle Falls Generating Station is the State's only utility-scale wood-fired biomass electric generating station. It produces an electrical output of 53 MW from sawmill

280. EA Engineering, Science, and Technology, *CDR Evaluation Study*, 9.

281. Eklavya Gupte, "World's Largest Direct Air Capture Plant Enters Operation in Iceland," *S&P Global*, August 5, 2024, https://www.spglobal.com/commodity-insights/en/news-research/latest-news/energy-transition/050824-worlds-largest-direct-air-capture-plant-enters-operation-in-iceland.

282. Sasha Ranevska, "Occidental's Stratos DAC Hub To Launch Operations By The End Of 2025," *Carbon Herald*, August 8, 2025, https://car2bonherald.com/occidentals-stratos-dac-hub-to-launch-operations-by-the-end-of-2025.

283. 280 Earth, accessed October 26, 2025, https://280.earth.

284. *Id*.

285. Analysis reveals that the low carbon intensity of Washington"'s electrical grid only brings down the cost of adsorbent DACS operations to below $800 per MT CO_2. Pett-Ridge et al., *Roads to Removal*, 7–12.

286. *Id*. at 7–6.

287. *See id*. at 7–11.

288. A facility's capture and storage of biogenic CO_2 is completely distinct from the capture and storage of a facility's nonbiogenic, fossil CO_2. *See generally* Sarah L. Nordahl et al., "Carbon Accounting for Carbon Dioxide Removal," *One Earth* 7, no. 9 (2024): 1494–500, https://doi.org/10.1016/j.oneear.2024.08.012.

289. *See* Washington Climate Partnership, *Draft CCAP*, 189, 195.

Figure 16. Photo of wood pile, WA. *Carbon Containment Lab.*

wood waste and emitted 442,112 MT of biogenic CO_2 in 2023.[290] Larger-scale electric utility BECCS projects are being deployed domestically and abroad. For example, the Drax Power Station BECCS project in the UK is slated to capture 8 million MT CO_2 per year when its two carbon capture units are operational in 2030.[291]

The State has identified the retrofitting of pulp and paper facilities with CCS as another near-term BECCS opportunity.[292] Similar to bioenergy facilities, pulp and paper facilities have large centralized biomass-combustion systems and high-quality thermal energy available that make them particularly strong candidates for conversion into BECCS facilities.[293]

Washington counts 21 pulp and paper mills, sawmills, and wood product manufacturing plants that both recorded biogenic CO_2 emissions greater than the 45Q emission threshold for industrial facilities in 2023 and are still operating today.[294] That year, these facilities reported

290. Ecology, "GHG Reporting Program."

291. Todd Bush, "UK's Drax Eyes U.S. for Bioenergy CCS Expansion Drive," Decarbonfuse, January 1, 2025, accessed October 26, 2025, https://decarbonfuse.com/posts/uk-s-drax-eyes-u-s-for-bioenergy-ccs-expansion-drive.

292. *Id*. at 195

293. *Id*. at 195.

294. Ecology, "GHG Reporting Program." Two of the 23 facilities originally in this list have since shut down: McKinley Paper Co.'s Port Angeles paper mill closed in 2024, while WestRock CP, LLC's Tacoma kraft mill closed in September 2023. *See* "McKinley to Close Port Angeles Paper Mill, Nearly 200 Workers Get 60-Day Notice," PaperAge, June 28, 2024, https://www.paperage.com/2024news/06-28-2024mckinely-paper-closing-port-angeles-mill.html; "WestRock Announces Plans to Close Tacoma, Wash., Paper Mill," WestRock.

cumulative biogenic CO_2 emissions of 4.6 million MT CO_2.[296] Washington's four active kraft mills were responsible for 65% of these emissions (3.0 million MT CO_2).[297] It is expected that at least some of Washington's pulp and paper facilities will convert into BECCS facilities because the Draft CCAP recommends that the State support early movers who partner with CO280, a project developer based in British Columbia that recently signed a deal with Microsoft to scale up CDR+S in the industry.[298]

Mechanically thinned biomass from wildfire-prone forests represents the largest potential long-term source of renewable biomass feedstock for both new and converted BECCS facilities. The U.S. Forest Service's 2022 10-year wildfire-crisis strategy sets out an ambitious plan to treat 70 million acres of public and private forests in the American West against the risk of wildfires.[299] **Modeling suggests that steady implementation of this plan could generate 12.0 million bone-dry metric tons (BDMT) of non-merchantable waste biomass in Washington each year which, if used as feedstock for BECCS facilities, could represent an annual offsetting opportunity of 22.1 million MT CO_2—nearly double the amount of offsetting that the State is projected to need to achieve net-zero.**[300] If uncaptured, this carbon would be reemitted to the atmosphere via combustion or decay.

Chapter 9: Siting Prioritization refines the above geospatial analysis of CO_2 sources, comparing their locations to recommended areas of interest for GCS.

296. Ecology, "GHG Reporting Program."

297. *Id*.

298. Washington Climate Partnership, *Draft CCAP*, 195; *see also* $CO_2$80, "$CO_2$80 Signs Landmark 3.69 Million Tonne Agreement with Microsoft to Scale-up Carbon Dioxide Removal in the US Pulp and Paper Industry," *PR Newswire*, April 11, 2025, https://www.prnewswire.com/news-releases/co280-signs-landmark-3-69-million-tonne-agreement-with-microsoft-to-scale-up-carbon-dioxide-removal-in-the-us-pulp-and-paper-industry-302426170.html.

299. Forest Service, *Confronting the Wildfire Crisis* (U.S. Department of Agriculture, 2022), 1, http://fs.usda.gov/sites/default/files/Wildfire-Crisis-Implementation-Plan.pdf.

300. *See generally* Pett-Ridge et al., "Chapter 6: Biomass Carbon Removal and Storage (BiCRS)," *Roads to Removal* (analyzed by the Carbon Containment Lab).

Table 4. Biogenic CO_2 Emissions from 45Q-Eligible Potential BECCS Facilities

ID	Facility	Sector	Road Distance from CRBG (miles)	Biogenic CO_2 emissions (MT)
B-01	Kettle Falls Generating Station - Kettle Falls	Biomass Electric Power Generation	51	442,112
B-02	Boise Cascade Wood Products, LLC. Kettle Falls Lumber - Kettle Falls	Cut Stock, Resawing Lumber, and Planing	50	56,520
B-03	Nippon Dynawave - Longview	Kraft Mills	0	1,197,530
B-04	Packaging Corporation of America - Wallula	Kraft Mills	0	219,269
B-05	Port Townsend Paper Corporation - Port Townsend	Kraft Mills	117	491,477
B-06	WestRock LLC - Longview	Kraft Mills	0	1,129,402
B-07	SDS Lumber Company - Bingen	Miscellaneous Wood Product Manufacturing	0	47,338
B-08	Vaagen Bros. Lumber, Inc. - Colville	Miscellaneous Wood Product Manufacturing	52	33,076
B-09	Inland Empire Paper Company - Spokane	Newsprint Mills	1	15,753
B-10	Boise Cascade Wood Products, LLC - Kettle Falls	Reconstituted Wood Product Manufacturing	52	56,228
B-11	Guy Bennett Lumber Company - Clarkston	Sawmills	0	14,481
B-12	Hampton Lumber Mills Washington Inc. - Darrington	Sawmills	148	82,200
B-13	Hampton Lumber Mills Washington Inc. - Morton	Sawmills	43	29,133
B-14	Interfor US, Inc. - Port Angeles	Sawmills	144	39,023
B-15	Port Angeles Hardwood LLC - Port Angeles	Sawmills	143	21,342
B-16	Sierra Pacific Industries - Aberdeen	Sawmills	11	202,493
B-17	Sierra Pacific Industries - Burlington - Mount Vernon	Sawmills	145	309,509
B-18	Sierra Pacific Industries - Centralia	Sawmills	10	39,000
B-19	Sierra Pacific Industries - Shelton	Sawmills	44	58,498
B-20	Weyerhaeuser Raymond Lumber - Raymond	Sawmills	17	32,795
B-21	Hampton Lumber Mills Washington Inc. - Randle	Softwood Veneer and Plywood Manufacturing	60	56,677
B-22	Rainier Veneer, Inc. - Spanaway	Softwood Veneer and Plywood Manufacturing	55	13,241
			Total	**4,587,097**

Our analysis of CCS (with GCS) as a potential CDR technology focuses on biogenic CO_2; since these fall beyond the scope of the CCA, their capture presents an opportunity to generate negative emissions that can offset residual CO_2 emissions elsewhere in the economy. Road distance is measured to the nearest boundary of the CRBG. Facilities are sorted by sector and then alphabetized. Facilities are displayed by their ID in Figure 17, page 75. All data is from 2023.[295]

295. Ecology, "GHG Reporting Program."

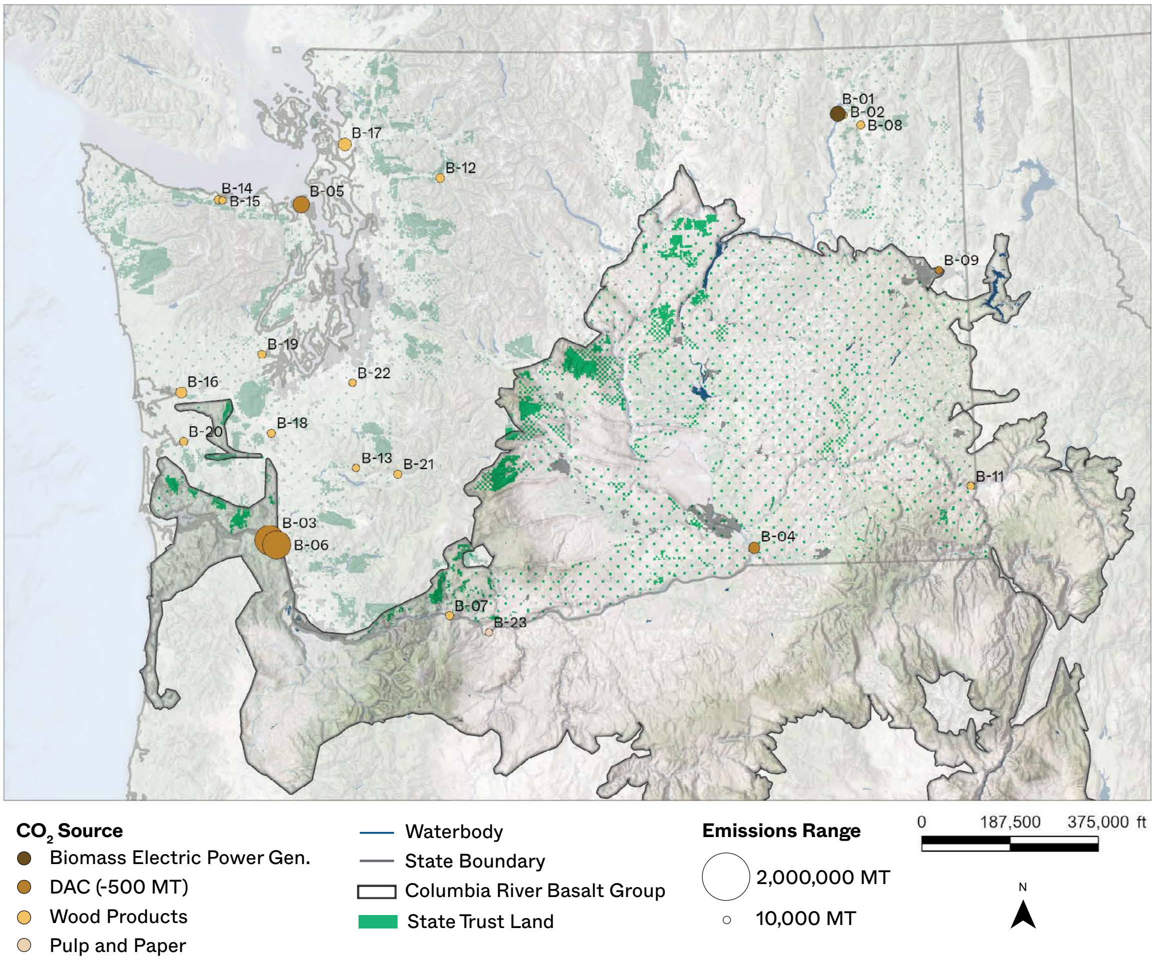

Figure 17. Map displays potential DAC and BECCS CO_2 sources for GCS, particularly their potential to offset residual CO_2 emissions and their locations in relation to the CRBG. Volume of CO_2 emissions and road distance for potential BECCS facilities are provided in Table 4, page 73. The CO_2 removal rate at the 280 Earth facility is taken from their website. Biogenic CO_2 emissions data for potential BECCS facilities is from 2023.[301]

Conclusion

Prior modelling has shown that at least 6.2 million MT CO_2 will need to be sequestered via GCS to offset residual non-CO_2 emissions.[302] This stocktake indicates that millions of additional MT of biogenic and nonbiogenic CO_2 could be sequestered geologically if the option were available.

- Overall, assuming 2023 levels, the facilities assessed in this chapter emit 20.9 million MT of CO_2 annually: 16.3 million MT of nonbiogenic CO_2 (7.3 million MT within 70 miles of the CRBG) and 4.6 million MT of biogenic CO_2 (3.7 million MT within 70 miles of the CRBG).

301. Ecology, "GHG Reporting Program"; 280 Earth.

302. Evolved Energy Research, *Net-Zero Northwest*, 238.

- The BECCS industry should prosper in Washington. If the USFS's plan to mitigate wildfire risk through mechanical thinning could generate 12.0 million BDMT of residual biomass annually. This feedstock would provide new and existing BECCS facilities with an annual offsetting opportunity of 22.1 million MT of biogenic CO_2[303]

- **Applying the benchmark CO_2 capture rate of 90% suggests that 38.7 million MT CO_2 (90% of 43.0 million MT CO_2[304]) could ultimately become available for GCS annually: 18.8 million MT from existing nonbiogenic and biogenic emissions at suitable point sources, and 19.9 million MT of potential biogenic emissions from the utilization of biomass thinned from forests at risk of wildfire.[305]**

The State should consider preparing for the volumes of CO_2 captured at point sources or drawn down from the atmosphere that will need GCS by 2050.

303. *See generally* Pett-Ridge et al., "Chapter 6: Biomass Carbon Removal and Storage (BiCRS)," *Roads to Removal* (analyzed by the Carbon Containment Lab).

304. For the avoidance of doubt, this 43.0 million MT CO_2 represents the sum of annual nonbiogenic and biogenic CO_2 emissions from the following sources: grid electrical power and commercial electrical power natural gas plants, as well as the Spokane Waste-to-Energy Plant (8.8 million MT CO_2); industrial facilities (7.5 million MT CO_2); currently operating biomass conversion facilities suitable for CCS (4.6 million MT CO_2); and the processing of biomass resulting from wildfire mitigation at new and existing BECCS facilities (22.1 million MT CO_2). We used emissions data reported to Ecology when available and, when not, data reported to the Energy Information Administration.

305. A 90% capture rate is an "historical benchmark" that is "ubiquitously adopted." However, it is also an "artificial limit" that does not reflect the technological ability of capture systems to operate at higher capture rates. *See* Paul Feron et al., *Towards Zero Emissions CCS in Power Plants Using Higher Capture Rates or Biomass* (Cheltenham, UK: IEA Greenhouse Gas R&D Programme, 2019), 1, https://publications.ieaghg.org/technicalreports/2019-02%20Towards%20Zero%20Emissions%20CCS%20from%20Power%20Stations%20using%20Higher%20Capture%20Rates%20or%20Biomass.pdf. We do not attempt to apply facility-specific capture rates because these are heavily influenced by conditions that are not publicly available (e.g. CO_2 concentrations, flue gas contaminants, and on-site waste heat availability). *See* Jonathan M. Moch et al., "Carbon Capture, Utilization, and Storage: Technologies and Costs in the U.S. Context," Belfer Center, January 2022, 4–8, https://www.belfercenter.org/sites/default/files/pantheon_files/files/publication/Brief_CCUS_FINAL.pdf.

KEY TAKEAWAYS

- Washington's GHG emissions reductions are currently not on pace. The January 2025 *Washington State Greenhouse Gas Emissions Inventory: 1990–2021* shows the State overshot its emission-reductions goals in 2021 by 5.6 million MT CO_2e. Action must be taken to get on track to achieving net-zero emissions by 2050.

- Some facilities desiring to continue operating in the State cannot fully decarbonize without CCS. To make headway with reducing emissions in the near-term, the State should consider that natural gas power plants far from retirement and hard-to-decarbonize industrial facilities have the greatest need and suitability for CCS with GCS.

    - Assuming 2023 emissions levels, 16.3 million MT of nonbiogenic CO_2 emissions from the power plants and industrial facilities identified in this chapter would require CCS with GCS annually. 7.3 million MT of these emissions are located within 70 miles of the CRBG.

- Deploying CCS with GCS at new and existing biomass conversion facilities could generate the negative emissions necessary to offset the State's projected residual emissions—notably process and fugitive emissions in the industrial sector, agricultural emissions, and fugitive fossil fuel emissions—and meet climate goals.

    - Assuming 2023 emissions levels, 4.6 million MT of biogenic CO_2 are available for CCS with GCS annually—and the generation of a corresponding volume of negative emissions—if the biomass conversion facilities identified in this chapter are retrofitted. 3.7 million MT of these emissions are located within 70 miles of the CRBG.

    - Implementation of the USFS's plan to mitigate wildfire risk through mechanical thinning could generate 12.0 million MBDT of residual biomass annually. This feedstock could provide new and existing BECCS facilities with an annual offsetting opportunity of 22.1 million MT of biogenic CO_2. This volume alone could offset all of Washington's projected residual emissions, and it strongly justifies the Draft CCAP's plan of incentivizing investment in GCS now to support future CDR+S.

- In sum, if CO_2 emissions at natural gas power plants and hard-to-decarbonize industrial sources operating to date persist at 2023 levels, and if BECCS reaches its full potential, then application of a 90% capture rate indicates 38.7 million MT of captured CO_2 could become available for GCS sited on state trust lands annually. If DACCS scales in the state, this volume will be larger.

7. Geologic Setting

RECAP FROM PRIOR CHAPTERS

- The State has vast onshore and offshore basalt resources, which can permanently and safely sequester CO_2.
- The CRBG is the State's most prominent basalt formation. It underlies most of eastern Washington and, given its unique characteristics, has potential to sequester 40 billion MT CO_2 for millennia.
- The CRBG is rich in the elements needed for carbon mineralization—the chemical process in which CO_2 precipitates into carbonate minerals when exposed to silicate minerals.
- Injecting CO_2 for GCS into basalt formations like the CRBG is superior to—safer and more permanent than—conventional storage methods because carbon mineralization quickly traps the CO_2 within the basalt's pore space and forms rock.

Geologic Setting

Introduction

Washington hosts several basalt provinces formed over millions of years of volcanic activity. This volcanism created vast accumulations of mafic rock with the reactive chemical and structural characteristics required for permanent GCS. The most prominent province is the CRBG, which underlies much of eastern Washington. The CRBG includes several major formations—the Grande Ronde, Wanapum, Saddle Mountains, Steens, Imnaha, Picture Gorge, and Prineville Basalts—which together comprise massive layered flows.[306] (See Figure 18.)

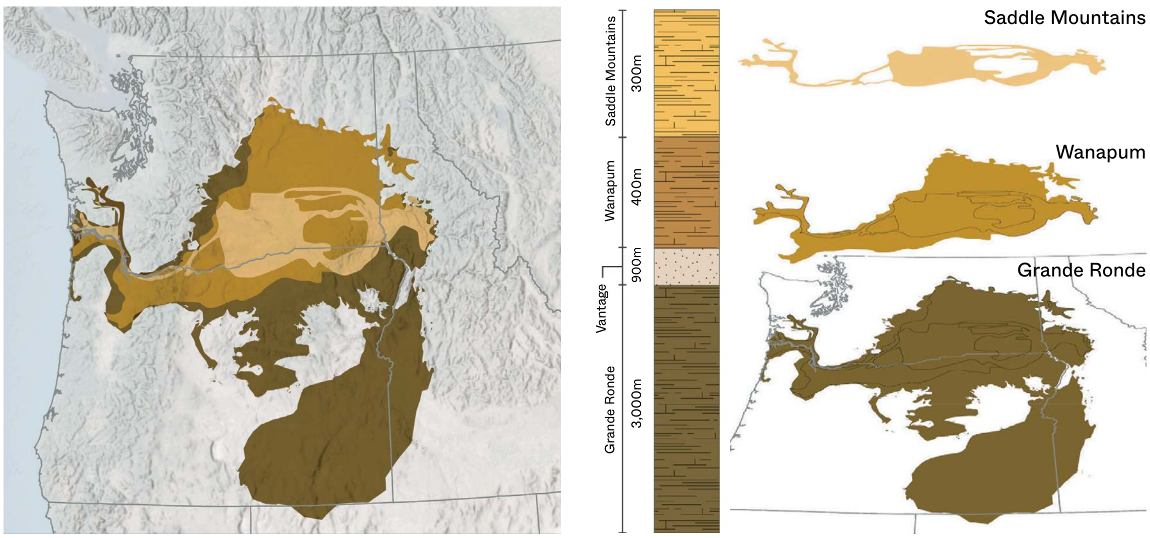

Figure 18. Generalized geologic map of the CRBG showing surface extents of the major basalt formations—Grande Ronde, Wanapum, and Saddle Mountains—and their layered stratigraphy with approximate depths. Surface extents visualized axonometrically.[307]

Along the western edge of the State, the Coast Range Basalt Province—part of the Siletzia terrane—comprises Eocene marine basalts, including the Crescent, Siletz River, Black Hills, Willapa Hills, and Metchosin formations.[308] These tholeiitic basalts, formed in an oceanic environment millions of years ago, now underlie large areas of western Washington and extend offshore beneath the continental margin.[309]

306. Camp et al., *Field Trip Guide to the CRBG*, 88.

307. Adapted from Svadlenak and Florea, *Groundwater Chemistry in the Columbia River Basalt Group,* 1.

308. David Peterson and Ray E. Wells, "Geologic History of Siletzia, a Large Igneous Province in the Oregon and Washington Coast Range: Correlation to the Geomagnetic Polarity Time Scale and Implications for a Long-Lived Yellowstone Hotspot," *Geosphere* 10, no. 4 (August 2014): 692–719. https://doi.org/10.1130/GES01018.1.

309. *Id*.

Washington's Cascade Range volcanic basalts include younger, Holocene flows derived from shield volcanoes, cinder cones, and monogenetic volcanic fields.[310] Notable examples include the Marble Mountain-Trout Creek Hill field and West Crater, which are characterized by fresh basaltic material favorable for rapid carbon mineralization.[311]

Together, these onshore and offshore basalt formations represent a diverse set of geological environments with substantial potential for GCS. Their distribution across the State, coupled with varying ages and chemistries, offers multiple pathways for implementing large-scale GCS.[312] This report focuses on the CRBG, though other formations should later be evaluated when developing a statewide siting strategy.

The Columbia River Basalt Group: A World-Class Storage Resource

The CRBG is among the most promising basalt formations globally for GCS.[313] It formed between roughly 17 and 6 million years ago when intense flood basalt eruptions breached long fissure systems across eastern Washington and parts of Oregon and Idaho. The CRBG and its related basalt units cover more than 80,000 square miles—representing one of the largest continental flood basalt provinces on Earth—and reach thicknesses of up to three miles.

The CRBG offers exceptional targets for carbon mineralization storage due to its geochemistry and structure. As a primarily mafic rock, basalt contains abundant divalent cations—calcium, magnesium, and iron—that react with water-dissolved or supercritical CO_2 to form stable carbonate minerals.[314]

The CRBG is composed of more than 300 individual basalt flows.[315] Each individual lava flow typically displays a four-part structure: (1) a highly fractured flow bottom, a dense and thick flow interior composed of (2) a fractured entablature zone and (3) colonnade, and (4) a rubbly or brecciated flow top. The repeated eruption and cooling of a lava flow and subsequent burial by younger flows resulted in a thick stack of repeating porous and permeable flow top and flow bottom breccias overlain by dense flow interiors of overlying lava flows. (See Figure 19.) This layered architecture provides numerous and extensive natural reservoirs and seals. The porous, permeable flow tops and flow bottom breccias form ideal injection zones for CO_2, while the dense interiors and bases of the overlying flows can act as confining caprocks that restrict the vertical migration of injected CO_2.[316]

310. James G. Smith, *Geologic Map of Upper Eocene to Holocene Volcanic and Related Rocks in the Cascade Range, Washington* (Washington, DC: U.S. Department of the Interior, 1989), https://pubs.usgs.gov/of/1989/0311/report.pdf.

311. *Id*.

312. *See, e.g.*, "CCUS Western States, Washington," CUSP West, accessed November 13, 2025, https://www.cuspwest.org/washington.

313. Madalyn S. Blondes et al., *Carbon Dioxide Mineralization in the United States* (Reston, VA: U.S. Geological Survey, 2019), 5, https://pubs.usgs.gov/sir/2018/5079/sir20185079.pdf.

314. *See generally* White et al., "Quantification of CO_2 Mineralization at the Wallula Basalt Pilot Project."

315. Camp et al., *Field Trip Guide to the CRBG*, 3–18.

316. *Id*.

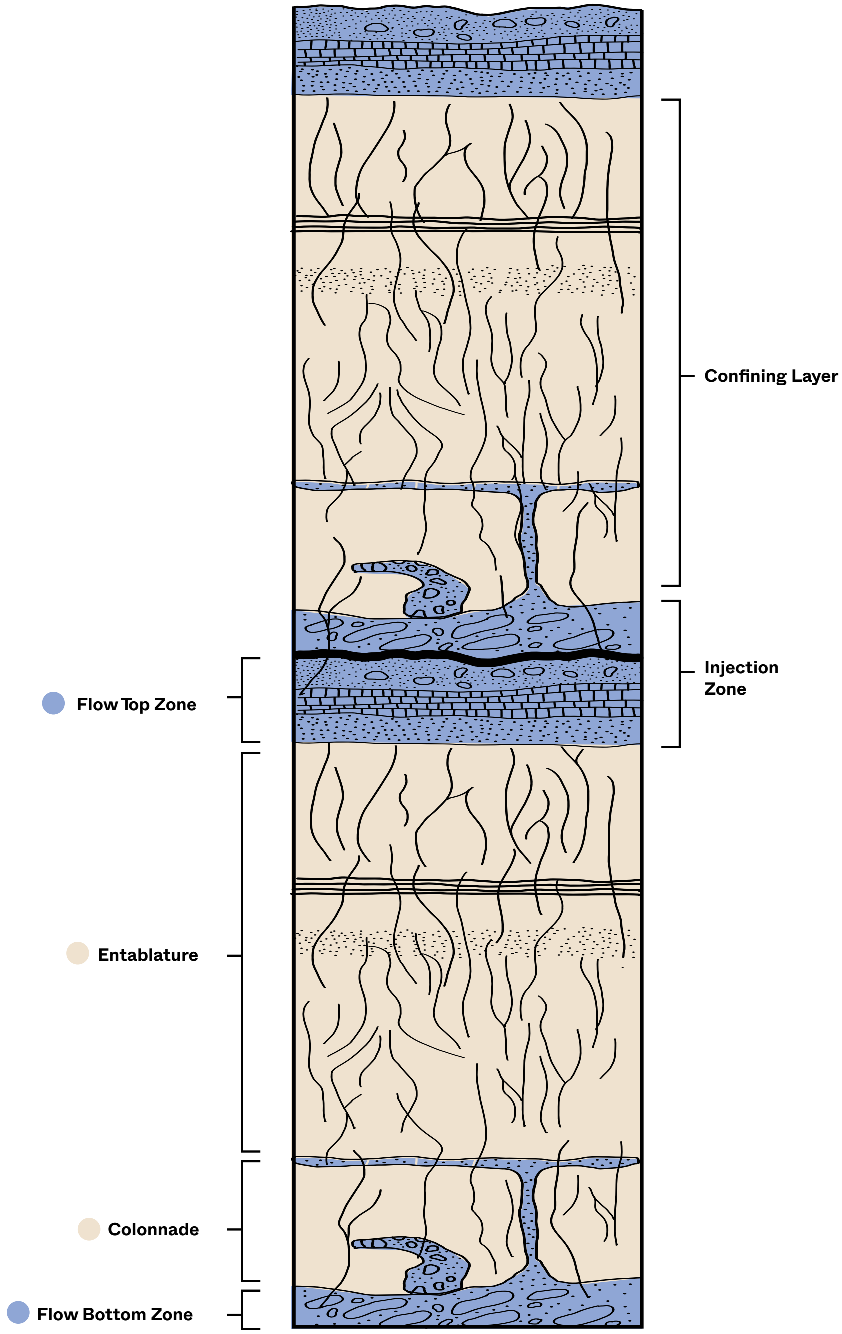

Figure 19. Schematic structure of two stacked lava flows in the CRBG. The basalt formations in the CRBG are composed of layered stacks of lava flows, each of which has the characteristic structure shown above. The flow tops and overlying flow bottoms are porous and permeable and targets for CO_2 injection, while the dense flow interiors (entablature and colonnade) serve as impermeable seal intervals that prevent CO_2 migration.[317]

317. Adapted from Stephen P. Reidel et al., "The Columbia River Basalt Group of Western Idaho and Eastern Washington—Dikes, Vents, Flows, and Tectonics Along the Eastern Margin of the Flood Basalt Province," *Exploring the Geology of the Inland Northwest*, Geological Society of America Field Guide 41, ed. R.S. Lewis and K.L. Schmidt (Boulder, CO: Geological Society of America, January 2016), 132, https://doi.org/10.1130/2016.0041(04).

Figure 19 presents a diagram of the main features of a typical CRBG basalt flow, which can vary in thickness from 100 to 200 ft. The key elements are:

- **Flow Top Zone:** This is the top of the flow. It is typically vesicular due to degassing of the molten basalt lava, rubbly, and brecciated. This combination greatly increases the hydraulic conductivity of the section with porosities up to 80%[318] but likely averaging 10–25%.[319] As such, this top flow zone alone transmits groundwater effectively.

- **Entablature:** This part of the flow is randomly fractured, blocky, with fanning columns, minor vesiculation, and has a typical porosity of less than 1%. The entablature forms part of the dense flow interior that serves as a caprock for injected CO_2.

- **Colonnade:** The dense interior of the flow may include a colonnade (normally 6-sided basalt columns) with very little primary porosity of less than 1%. Colonnades have the potential to act as a caprock for injected CO_2.

- **Flow Bottom Zone:** This section is often vesicular and consists of rubble and breccia or pillow-palagonite complexes. Pillow-palagonite complexes form when the lava flow encounters standing water during an eruption and is rapidly quenched, forming glassy and highly fractured surfaces that are highly porous and transmissive (e.g., high hydraulic conductivity can exceed 10,000 feet per day [ft/d]). When the bottom of one flow overlies the top of the preceding flow, a permeable "interflow" zone is created.

Hydrogeologic Criteria for Injecting CO_2 Into Basalt

The feasibility of safely and permanently injecting CO_2 into basalt formations is reliant on meeting certain structural criteria, specifically hydrogeologic criteria that balance injectivity, mineralization potential, and long-term containment. These criteria differ between supercritical CO_2 injection and carbonated water injection, reflecting the distinct physical and chemical behavior of the CO_2 used in each method. (See Table 5.)

Chapter 3: Injection Techniques and Mineralization Science distinguishes between the operational demands (e.g., energy and water) of these two techniques.

318. Jacob Covault et al., "Geologic Framework for the National Assessment of Carbon Dioxide Storage Resources: Columbia Basin of Oregon, Washington, and Idaho, and the Western Oregon-Washington Basin," *U.S. Geological Survey Open-File Report 2012–1024–D*, ed. P. D. Warwick and M. D. Corum, 19 (2013), http://dx.doi.org/10.3133/ofr20121024d.

319. Signe K. White et al., "Quantification of CO_2 Mineralization at the Wallula Basalt Pilot Project," *Environmental Science & Technology*, 54 no. 22 (2020), 14609–16, https://pubs.acs.org/doi/10.1021/acs.est.0c05142.

In general, safe and permanent sequestration requires adequate lateral continuity of suitable basalt flows, the absence of major fault systems that could form leakage pathways or lateral flow barriers, effective sealing mechanisms such as dense flow interiors or interbedded sedimentary layers, and appropriate depth and permeability conditions.[320] Table 5 below summarizes the key subsurface requirements for both injection techniques, providing a framework for identifying "sweet spots" for injection. These criteria should be considered at both the formation and regional (i.e., geologic unit) scale.

Table 5. List of Injection Criteria for Supercritical CO_2 and Carbonated Water Injection Techniques

Parameter	Supercritical CO_2	Carbonated Water
Porosity & Permeability	Effective porosity >10%; permeability >500 millidarcy (mD)	Lower values acceptable; dissolution aids transport; >100–200 mD preferred
Reservoir Thickness	>30 ft (preferably thicker to promote plume spread and reservoir capacity)	>10–20 ft may suffice due to slower injection and water saturation
Caprock Seal	>100 ft of low-permeability rock required to trap buoyant CO_2	A thick seal is unnecessary due to absence of CO_2 buoyancy; capillary sealing still preferred
Water Chemistry	Injection zone must lie below potable aquifers; ideally saline/brackish	Same; brine preferred for chemistry and permitting
Transmissivity	>10^{-5} m^2/s (critical for injectivity and plume spread)	Lower values acceptable; injection rates are lower and more controlled

Note that criteria are generalized.

Formations Suitable for CO_2 Injection and Storage

The main stratigraphic units of basalt that can be correlated over large lateral distances are, from oldest to youngest, the Grande Ronde, Wanapum, and Saddle Mountains basalts. The Saddle Mountains basalt is not considered an attractive target for GCS based on its shallow depth and prevalence of groundwater aquifers utilized for domestic and agricultural use. Therefore, we focus on evaluating the Grande Ronde and Wanapum basalts in further detail.

Grande Ronde Basalt

The Grande Ronde Basalt is especially well suited for large-scale injection because it is the thickest and most widespread formation in the CRBG. It contains numerous flow units with

320. *See generally* McGrail et al., "Injection and Monitoring at the Wallula Basalt Pilot Project."

reactive mineralogy and sufficient secondary porosity to support high injection rates and promote rapid mineralization. The brecciated flow tops within the basalt stack are laterally continuous and can be traced across wide areas, providing potential transmissive zones for CO_2 injection. The Grande Ronde's depth, lateral continuity, and structural confinement in synclines (downwarped troughs) also provide the necessary conditions to sustain dense-phase injection and minimize upward migration.[321] Still, significant heterogeneity exists both between and within individual flows.

Because of the depth of the Grande Ronde across much of the basin, relatively few wells have been drilled to assess its geologic and hydrogeologic characteristics. However, several wells drilled for oil and gas exploration, natural gas storage, and deep aquifer tests demonstrate that the Grande Ronde is a favorable target for CO_2 injection and storage. For example, hydrologic testing of the Grande Ronde formation during drilling of the 100 Circles #1 well revealed multiple porous and permeable flow units that may serve as potential storage reservoirs, as well as thick, dense flow interiors that could provide effective seal intervals. Furthermore, formation evaluation in the Wallula Basalt Pilot Project well indicated sufficient injectivity of these zones, as well as favorable mineralogy for CO_2 mineralization over short time periods.[322] **Depending on the depth and subsurface characteristics, areas of the Grande Ronde may be amenable to injection and storage of supercritical or water-dissolved CO_2.**

Wanapum Basalt

The Wanapum Basalt overlies the Grande Ronde Basalt. Similar to the Grande Ronde, the Wanapum Basalt is composed of a thick sequence of flows, each of which has the characteristic features of brecciated flow tops and dense flow interiors. The stacked nature of the flows results in several permeable zones that may serve as injection targets and in overlying impermeable intervals that could form barriers to vertical CO_2 migration. **Either injection technique feasibly could be utilized in the Wanapum Basalt, but because of its shallower depths compared to the Grande Ronde, the areas feasible for supercritical CO_2 injection are more limited.**

Critically, both the Grande Ronde and Wanapum Basalt formations require additional subsurface characterization before CO_2 injection should occur.

Regions Suitable for CO_2 Injection and Storage

While many areas of the CRBG may be suitable for injection and storage of CO_2 based on the presence of ideal basalt formations containing stacked and laterally extensive lava flows, areas of the CRBG that are located far from secondary geologic features are understood to be generally more favorable for CO_2 storage.[323] In particular, geologic processes like folding, faulting, and erosion have affected the lava flows since they were deposited. Because these processes can disrupt the lateral continuity of the subsurface flows, they can potentially affect the storage suitability of injection zones. While active faults and anticlines are unfavorable to

321. Richard S. Jayne et al., "Geologic CO_2 Sequestration and Permeability Uncertainty in a Highly Heterogeneous Reservoir," *International Journal of Greenhouse Gas Control* 83 (April 2019): 128–39, https://doi.org/10.1016/j.ijggc.2019.02.001.

322. *Id*.

323. *See generally* McGrail et al., "The Wallula Basalt Sequestration Pilot Project."

GCS, synclines may be an ideal target, as their down warped structure preserves thick, laterally continuous basalt accumulations that can support GCS.

Two regions of the CRBG offer significant potential for GCS using both the supercritical and carbonated water injection techniques: the Yakima Fold Belt and the Palouse Slope. (See Figure 20.) These regions contain both the Grande Ronde and Wanapum Basalt formations described above. The Palouse Slope contains large and continuous zones of target injection layers that are far from significant geologic structures, such as major faults and folds. The Yakima Fold Belt is a more complicated region, but contains synclinal structures that may be favorable for GCS.

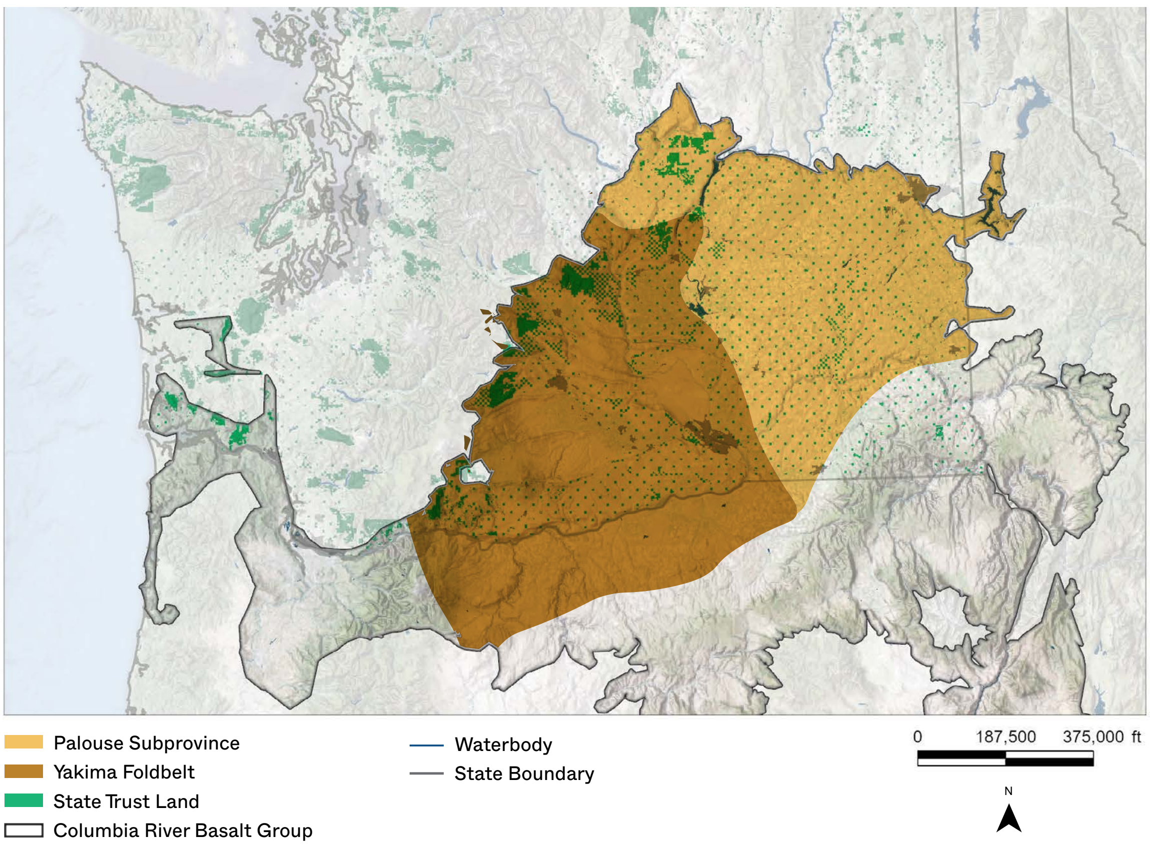

Figure 20. Subregions of the CRBG with favorable geologic characteristics for CO_2 storage: the Yakima Fold Belt and Palouse Slope.

Yakima Fold Belt

In south-central Washington, the Yakima Fold Belt creates a rhythmic series of synclines (downwarped troughs) and anticlines (uplifted ridges) that deform the basalt stack into a corrugated pattern. These folds, formed during and after the CRBG eruptions, create distinct structural provinces with varying suitability for GCS.[324] The synclines preserve thick and laterally continuous basalt accumulations at depth—ideal for broad and confined reservoirs with multiple reactive flow tops. In contrast, the anticlines tend to thin or expose flows,

324. Camp et al., *Field Trip Guide to the CRBG*, 18.

introduce faulting, and increase structural complexity, which can hinder containment.

The Horse Heaven Hills syncline, located between the Columbia River and Yakima River, is particularly promising, at least at a desktop level. The Horse Heaven Hills syncline is a structural block that is bounded by faults and folds on the north and south. Within the block, the stacked flows within the formations of the Grande Ronde, Wanapum, and Saddle Mountains basalts are continuous and relatively undeformed. This absence of major structures that could adversely affect the injection and storage of CO_2 indicates that this region could be favorable for GCS.

The Wallula Basalt Pilot Project, located on the eastern edge of the Fold Belt, provides one data point about the geologic characteristics of this region, but additional characterization is needed, such as to confirm depths, porosity, reservoir thickness, caprock seal properties, and transmissivity values.[325]

Palouse Slope

To the east of the Horse Heaven Hills syncline and the Tri-Cities, the Palouse Slope is another subregion of the CRBG that is relatively undeformed and may provide substantial opportunities for GCS. This region features gentler dipping and less deformed terrain with no major fault and fold systems. The Grande Ronde, Wanapum, and Saddle Mountains basalts are present in this area and have substantial thickness. Also, a lack of major geologic structures indicates continuous lateral extents of the lava flows, though several vertical dike swarms in the area may compartmentalize reservoirs and limit injection volumes.

The lack of deep wells in this region limits current understanding of the feasibility of injection and storage. However, the Wallula Basalt Pilot Project well just west of this region encountered favorable injection zones in brecciated flow tops and overlying caprocks. Given the lateral continuity of the CRBG formations, these subsurface conditions are expected to also be present throughout the Palouse Slope region.

Airborne Electromagnetic Survey: A Non-Invasive Subsurface Mapping of Hydrogeology

In 2024, the Carbon Containment Lab sponsored an airborne electromagnetic (AEM) survey by the contractor Geotech Ltd. to map the shallow hydrogeology in the Columbia River basin (2024 AEM Survey).[22] This was the first survey by modern geophysical remote sensing to cover a large, contiguous area of the basin with the goal of characterizing possible GCS sites.

The survey covered two 20 km by 20 km (≈ 12.4 miles x 12.4 miles) patches straddling the river, one in Washington and one in Oregon. (See Figure 21.) The three major flows of the CRBG—the Grande Ronde, Wanapum, and Saddle Mountains basalts—lie close to the surface in this part of the basin.

325. *See generally* McGrail et al., "Injection and Monitoring at the Wallula Basalt Pilot Project."

326. Michael Oristaglio, "Expert Workshop to Review Results from an Initial Geophysical Study of the CRBG," virtual lecture presented at the Carbon Containment Lab, New Haven, CT, March 19, 2024.

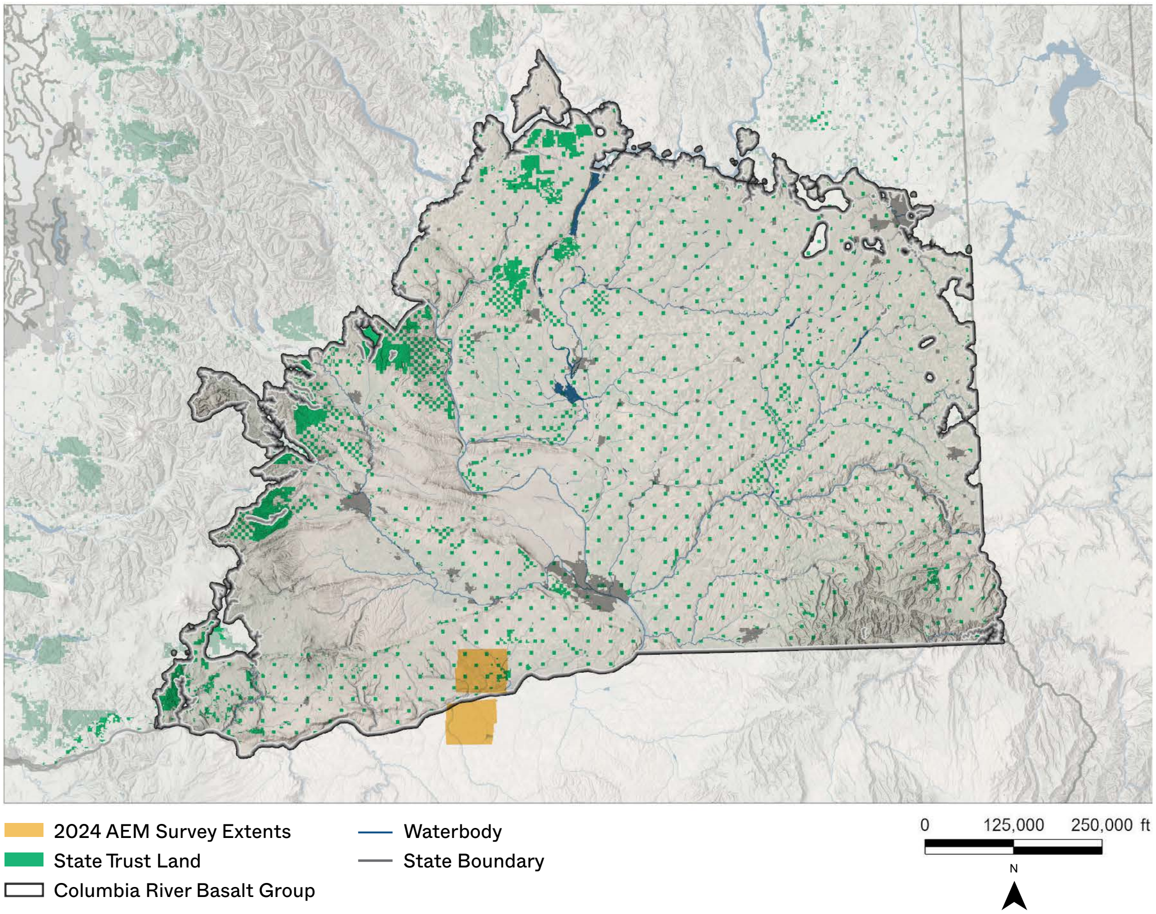

Figure 21. Approximate area of the high-resolution 2024 AEM Survey: two 20 km x 20 km (≈ 12.4 miles x 12.4 miles) patches, one in Washington and one in Oregon.

Hydrogeology of the Columbia River Plateau has been extensively studied by extrapolation of geologic maps drawn from surface outcrops and by interpolation of data (e.g., well logs and samples) between many water wells in the central part of the basin.[327] There are, however, only a few wells in the south-central part of the basin where the 2024 AEM Survey was flown. Moreover, extrapolation and interpolation over large areas can easily miss fine detail in geology, such as local sealing faults and other hydrologic barriers. The 2024 AEM Survey collected data along 80 flight lines at 500 m (≈ 1,640 ft) spacing between lines and with measurements made every 25 m (≈ 82 ft) along each line; this resolution is much higher than could be obtained by any practical sampling.

The 2024 AEM Survey produced a 3D image of electrical properties of the subsurface down to depths of approximately 600 m (≈ 1,969 ft) below ground surface (bgs), as shown in Figure 22.

327. Several reports have been issued by the U.S. Geological Survey, including Erick R. Burns et al., *Groundwater Status and Trends for the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho*, Scientific Investigations Report no. 2012–5261 (U.S. Geological Survey, 2012), https://doi.org/10.3133/sir20125261. The most comprehensive local studies were carried out by the Columbia Basin Groundwater Management Area of Adams, Franklin, Grant, and Lincoln Counties in a series of reports: *see, e.g.*, Terry Tolan et al., *Geologic Framework of Selected Sediment and Columbia River Basalt Units in the Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties, Washington, Edition 2* (The Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties, 2007).

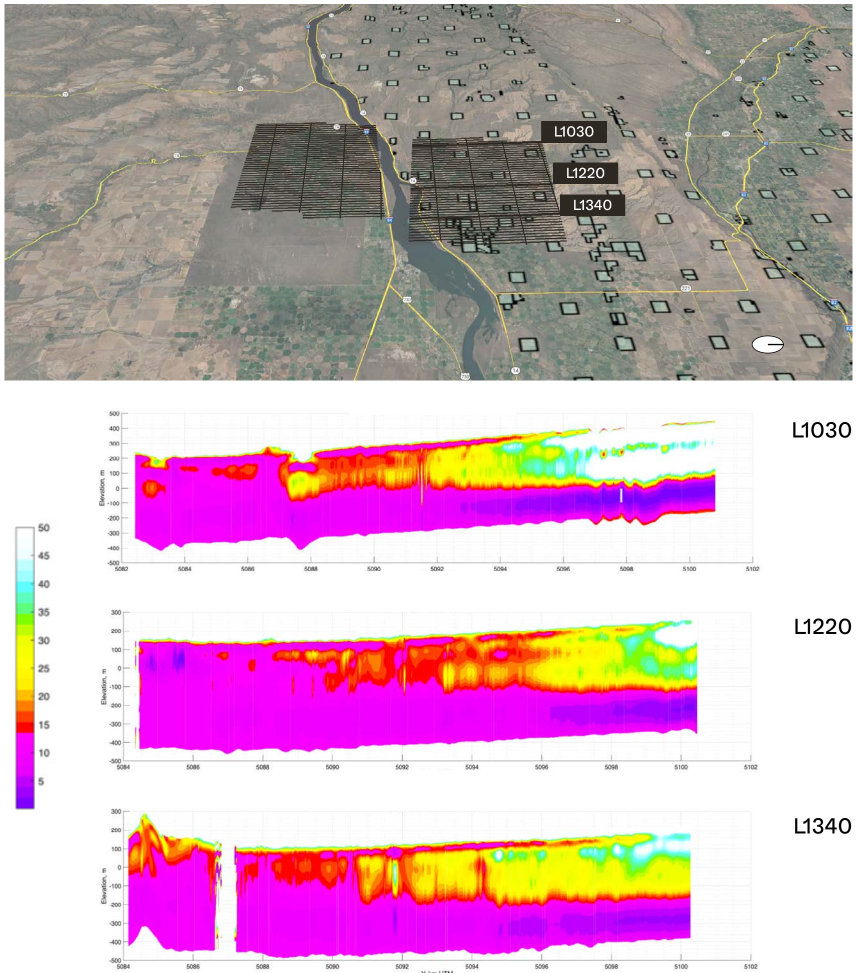

Figure 22. Results of the 2024 AEM survey. The upper figure shows the geographical location and extent of the survey area, with the Washington section on the right. The lower figure shows three cross sections of underground electrical resistivity from the Washington survey. Resistivity is color-coded to the scale on the left.[328]

Results show that airborne remote sensing can be both insightful and cost-effective in mapping the shallow subsurface over large areas of basalt. The results also correlate well with the known geology of the region, including in locations where drillers' logs have identified different members of the shallow basalt flows and intervening sedimentary deposits. A surprising result was the presence of a sharp transition from relatively high electrical resistivity in the shallow subsurface—typical of dry rock (massive basalt flow interiors) or rock saturated with fresh groundwater—to relatively low electrical resistivity at a depth of about 400 to 500 m below the surface (≈ 1,312–1,640 ft bgs). (See Figure 23.) Low electrical resistivity in volcanic or sedimentary rocks is usually associated with either more saline water (having higher dissolved solids) in the pore space or with high clay-mineral content in the rock matrix. **The possible presence of brackish or saline aquifers within 500 m of the surface has important implications for water use in the area, especially for potential use of the carbonated water injection technique.**

328. Oristaglio, "Expert Workshop."

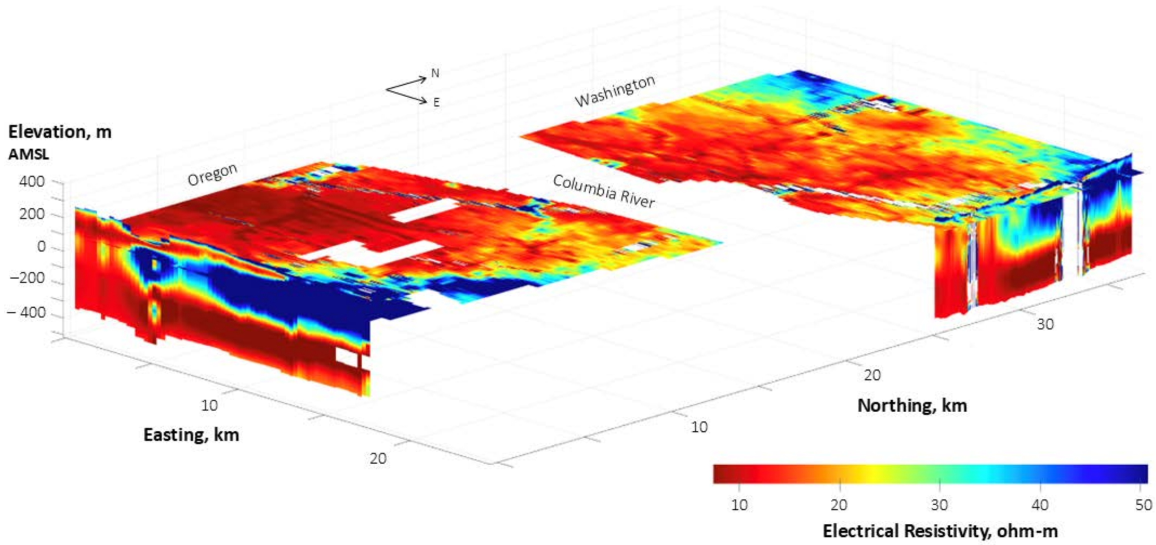

Figure 23. 3D image of electrical resistivity in the southern part of the Columbia River basin. View shows one horizontal slice at shallow depth and vertical slices in the E-W and N-S directions through a 3D image of subsurface electrical resistivity in a region straddling the Columbia River along the border between Washington and Oregon. Resistivity is color-coded to the scale at the lower right. High resistivity (blue) normally corresponds to dry rock or rock saturated with fresh groundwater. Low electrical resistivity (dark red) normally corresponds to rock saturated with more brackish or saline water with higher TDS. High or low resistivity at shallow depths is likely related to agricultural practices. The 3D image covers approximately 20 km by 20 km (≈ 12.4 miles x 12.4 miles) and extends from the surface topography to depths of about 600 m. Vertical exaggeration in the display is approximately 8:1. Blank zones are regions where data was not collected or was degraded by surface infrastructure. Image was produced from the 2024 AEM Survey.[329]

Based on these initial results, the Carbon Containment Lab teamed with several partners, including DNR, thanks to CCA grant funding from Commerce, for a project known as the Washington TrapRock Geophysical Research Surveys. The research team conducted an airborne survey in June 2025 that extends the original 2024 AEM survey area by another 1,000 km^2, or approximately 386 square miles. In addition, a 3D seismic survey was carried out in a 5 km by 5 km region (≈ 3 miles x 3 miles) that the 2024 AEM Survey identified as especially interesting for its GCS and water resource potential. Data from the 2025 surveys are still being analyzed. That project will conclude in June 2026, with a final report to be published in July.

329. Oristaglio, "Expert Workshop."

KEY TAKEAWAYS:

- The CRBG contains a thick laterally extensive sequence of lava flows with characteristics favorable to CO_2 injection and long-term storage. Two geologic formations, the Grande Ronde Basalt and the Wanapum Basalt, provide the best targets for CO_2 storage due to their depth, thickness, lateral extent, composition of numerous individual flows, and favorable geochemistry for CO_2 mineralization.

- The Yakima Fold Belt and the Palouse Slope, both of which contain the Grande Ronde and Wanapum basalt formations, are attractive subregions for GCS. The CRBG has undergone little deformation since emplacement on the Palouse Slope, while the Yakima Fold Belt contains the Horse Heaven Hills Syncline (among other synclinal features), which form favorable containers for GCS.

- Limited subsurface data about the deep CRBG formations in these regions creates a need for additional characterization, including stratigraphic test wells and geophysical surveys.

- The 2024 AEM Survey was the first survey by modern geophysical remote sensing to cover a large contiguous area of the Columbia basin with the goal of characterizing possible GCS sites. Results (1) show that airborne remote sensing can be both effective and cost-effective in mapping the shallow subsurface over large areas of basalt, (2) correlate well with the known geology of the region, and (3) reveal a sharp transition from relatively high electrical resistivity in the shallow subsurface to relatively low electrical resistivity at a depth of about 400 to 500 m (≈ 1,312–1,640 ft bgs).

- The Washington TrapRock Geophysical Research Surveys project builds on the positive results of the 2024 AEM Survey by expanding the airborne survey area and conducting a 3D seismic survey. Findings from the Washington TrapRock Geophysical Research Surveys will be published in summer 2026.

8. Hydrogeologic Setting

RECAP FROM PRIOR CHAPTERS

- CRBG flows typically display a layered structure: (1) a bottom brecciated zone, a dense and thick flow interior with (2) a fractured entablature zone and (3) colonnade, and (4) a rubbly or brecciated vesicular flow top. The flow tops and overlying flow bottoms are porous and permeable and possible injection zones. The entablature and colonnade have porosity less than 1% and can be a confining layer.

- Class VI regulations require CO_2 injections occur below the lowermost USDW, unless a waiver is obtained. An aquifer constitutes a "USDW," except if it contains more than 10,000 mg/L TDS or an insufficient quantity of groundwater to supply public drinking water. A permit applicant can obtain a waiver if an injection zone is not a USDW and is not hydraulically connected to one.

    - Groundwater developed in the upper portions of the CRBG has approximately 150 to 400 mg/L TDS, which constitutes a USDW and is potable.

- The carbonated water injection technique requires substantial volumes of water. A pilot-scale project injecting 1,000 MT CO_2 would need approximately 18.41 AFY total. A commercial-scale project aiming to sequester 1 million MT CO_2 annually would require 25 to 32 million MT of water (≈ 20,263–26,418 AFY or roughly 23 million GPD).

Hydrogeologic Setting

Introduction

This chapter evaluates the availability and quality of groundwater in the CRBG for GCS and summarizes the following evaluations and findings:

- a review of the geology and hydrogeology of the CRBG in central and eastern Washington, including accounts of well yields and depths;
- an evaluation of TDS concentrations within the CRBG aquifer system, compared to drinking water maximum contaminant levels (MCLs), irrigated crop tolerances, and UIC Class VI injection requirements;
- maps showing state trust lands relative to water well locations (data sources), known geologic structures in the CRBG, thickness of the underlying CRBG, proximity to federal and Tribal lands and groundwater users; and
- a reconnaissance-scale evaluation of groundwater development and water rights availability in the Columbia Basin.

Geology and Hydrogeology of the CRBG

An overview of the CRBG is presented in Chapter 7: Geologic Setting. This chapter focuses on the unique hydrogeologic attributes of the CRBG that result in productive regional aquifers that sustain a robust agricultural economy and supply water for domestic and municipal use in central and eastern Washington.[330] Key hydrogeologic considerations of the CRBG aquifers as they pertain to GCS are described below.

Hydrogeologic Characteristics of the CRBG Flows

Figure 19 (in Chapter 7: Geologic Setting) presents a diagram of the main features of a typical CRBG basalt flow: flow top zone, entablature, colonnade, and flow bottom zone. The flow bottom zone combines with the flow top zone of the underlying flow to create an "interflow zone" that is water-bearing.

Interflow zones can vary in thickness vertically and laterally, which affects their ability to transmit water horizontally. Interflow zones can also be truncated by faults that can impede or increase flow depending on how much the fault has annealed. However, decades of pumping groundwater from wells drilled into the CRBG and intercepting one or more interflow zones have proven that the CRBG aquifer system can, in certain locations, be the source of sustainable and high-yielding (e.g., 1,000 GPM) groundwater wells. For example, wells completed for Aquifer Storage and Recovery (ASR) purposes or municipal supply have yields as high as 1,400 GPM or more (for more than 90 days of pumping).

330. In addition to the published literature, insights into the hydrogeologic productivity of the CRBG are based on Summit Water Resources' 25 years of experience completing aquifer storage and recovery projects in the CRBG, predominantly in Oregon. Aquifer Storage and Recovery projects consist of injecting potable water into the CRBG for storage and recovering the banked water when needed.

The conceptual aquifer system of the CRBG consists of permeable interflow zones separated by less permeable flow interiors.[331] This, paired with the stratiform nature of the basalt sheet flows, creates a "stacked" series of confined or semiconfined aquifers which together comprise the CRBG aquifer system. Because interflow zones are laterally continuous with limited vertical permeability, they are a suitable candidate for GCS.

Vertical flow within the aquifer system is limited to zones where either a flow is truncated by an erosional window or flow pinch-out, faulting or folding has occurred, or CRBG flow units are cross-connected by wells.[332] Sedimentary aquifers overlie the CRBG in some locations, but the latter is used for domestic, municipal, and some irrigation sources and is not considered an appropriate target for GCS nor a viable source for a new groundwater right.

Impact of Geologic Structures on the Hydrogeology of the CRBG

Regional tectonic activity in the Pacific Northwest has deformed the CRBG in eastern Washington, resulting in folding and faulting. Numerous anticlines and synclines have been mapped across the State. (See Figure 24.) These structures can be simple or complex, and there can be double plunging structures. Faults that are annealed with clays act as an impermeable barrier to groundwater flow, as do faults that truncate interflow zones. More active, less annealed faults can enhance groundwater movement from deeper zones based on vertical flow head differentials. In fact, where the CRBG overlies marine sediments, faults that extend through both units enable saline water to vertically migrate into the CRBG aquifers in the deeper parts of the aquifer system. This concept is based on the presence of radon (as high as 500 picocuries per liter or more) in groundwater samples from the CRBG, as radon is not naturally occurring in basalts. This phenomenon has been observed in municipal water supply and ASR wells completed in CRBG aquifers in Oregon, but it is also possible along the western margins of the Columbia Basin.

Overall, faulting can also compartmentalize basalt and create a "bathtub" effect of the groundwater within the faulted compartment. This effect has been documented in Salem, Oregon, where a highly productive basalt section used for ASR purposes is so compartmentalized by faults that recharge is very predictable, resulting in a head rise, and recovery is also predictable with a drawdown in water level. The faulted and folded western half of the Columbia Basin may host a similar compartmentalization that would create a suitable container for GCS.[333]

Tectonic activities can also fold the CRBG sections and possibly increase vertical hydraulic conductivity due to the fracturing of the denser, more brittle sections of the basalt flows associated with the entablature and colonnades. This phenomenon has been documented in both the Washington and Oregon CRBG as a muted change in water level responses in different interflow zones that are separate from the zone being pumped. Even with measurable

331. Stephen C. Kahle et al., "Hydrogeologic Framework and Hydrologic Budget Components of the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho," *Scientific Investigations Report 2011-5124* (U.S. Geological Survey, 2011), 66, http://pubs.usgs.gov/sir/2011/5124.

332. *See generally* Terry L. Tolan et al., "A Summary of Columbia River Basalt Group Physical Geology and its Influence on the Hydrogeology of the Columbia River Basalt Aquifer System," (Othello, Washington: The Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties, June 2009).

333. R. C. Newcomb, "Storage of Ground Water behind Subsurface Dams in the Columbia River Basalt, Washington, Oregon, and Idaho," *U.S. Geological Survey Professional Paper 383-A* (1961), 15.

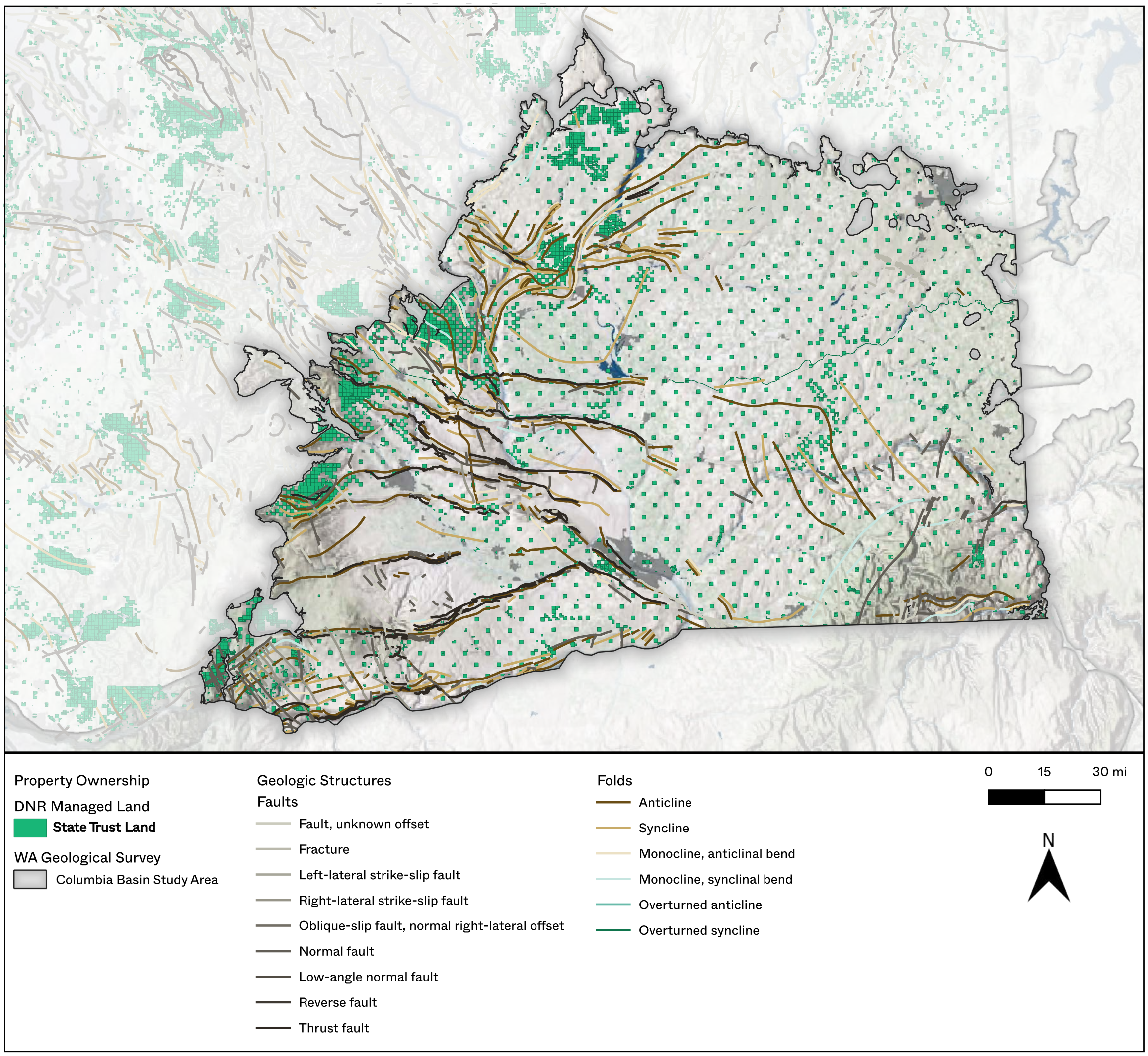

Figure 24. Map shows the Columbia Basin study area (outlined in black), state trust lands (in green), and faults and folds mapped throughout the basin (shades of brown).

responses in the different interflow zones during pumping, the difference between the horizontal hydraulic conductivity of the interflow zones to the vertical hydraulic conductivity through the basalt section is typically 10:1 in favor of horizontal flow.

Groundwater Flow in the CRBG in Eastern Washington

Groundwater flows through the CRBG aquifer system from upland recharge areas to surface water drainages, principally the Columbia River and other major tributaries such as the Snake and Yakima rivers.[334] Groundwater flow is impacted by topography, geologic structures, and natural recharge and discharge locations throughout central and eastern Washington. Figure 25 shows the major groundwater flow paths modeled by the U.S. Geological Survey for the

334. This section is based on the following U.S. Geological Survey reports on the CRBG aquifer system: Kahle et al., "Hydrogeologic Framework" and John J. Vaccaro et al., "Groundwater Availability of the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho," *U.S. Geological Survey Professional Paper 1817* (Reston, VA: U.S. Geological Survey, 2015), http://dx.doi.org/10.3133/pp1817.

Grande Ronde Formation of the CRBG. Figure 26 presents the overall recharge to the CRBG, which occurs mostly in the uplands at the edge of the basin where CRBG interflow zones intersect the surface, and rainfall is higher. Some artificial recharge to overlying sand and gravels and the shallow CRBG also occurs in lower elevation areas due to irrigation practices.

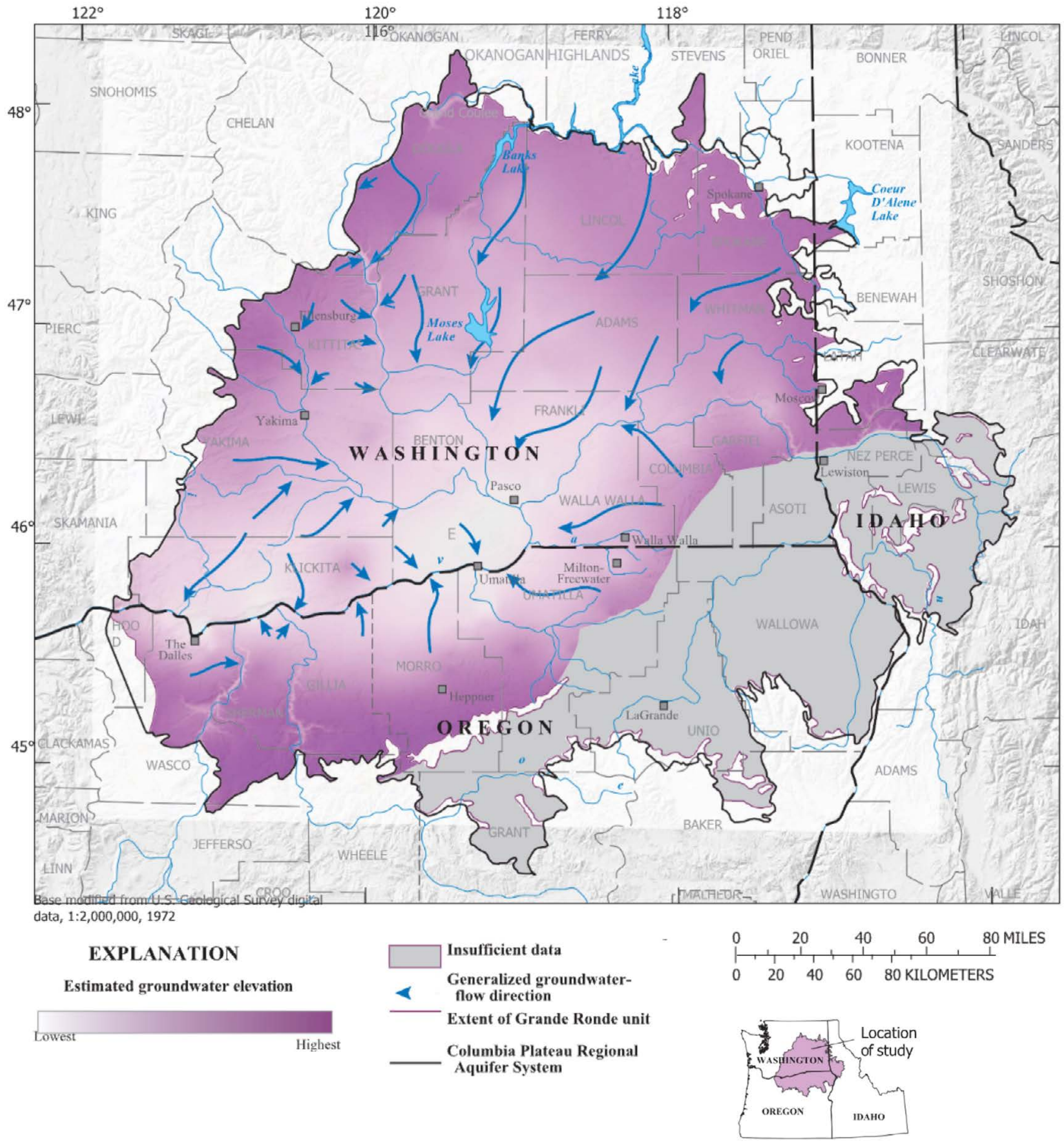

Figure 25. Map shows generalized groundwater levels and directions of lateral groundwater movement for the Grande Ronde unit within the Columbia Basin.[335]

The main aquifer systems are hosted in the three main basalt formations consisting of the Grand Ronde, Wanapum, and Saddle Mountains and their sedimentary intercalated units. Groundwater levels in the basalt generally parallel the land surface, and, when buried, parallel the dip of the basalt units. The groundwater level contours are smoother in the deeper part of the CRBG section, which has a low hydraulic gradient when compared to the uplands.

335. Kahle et al., "Hydrogeologic Framework," 28.

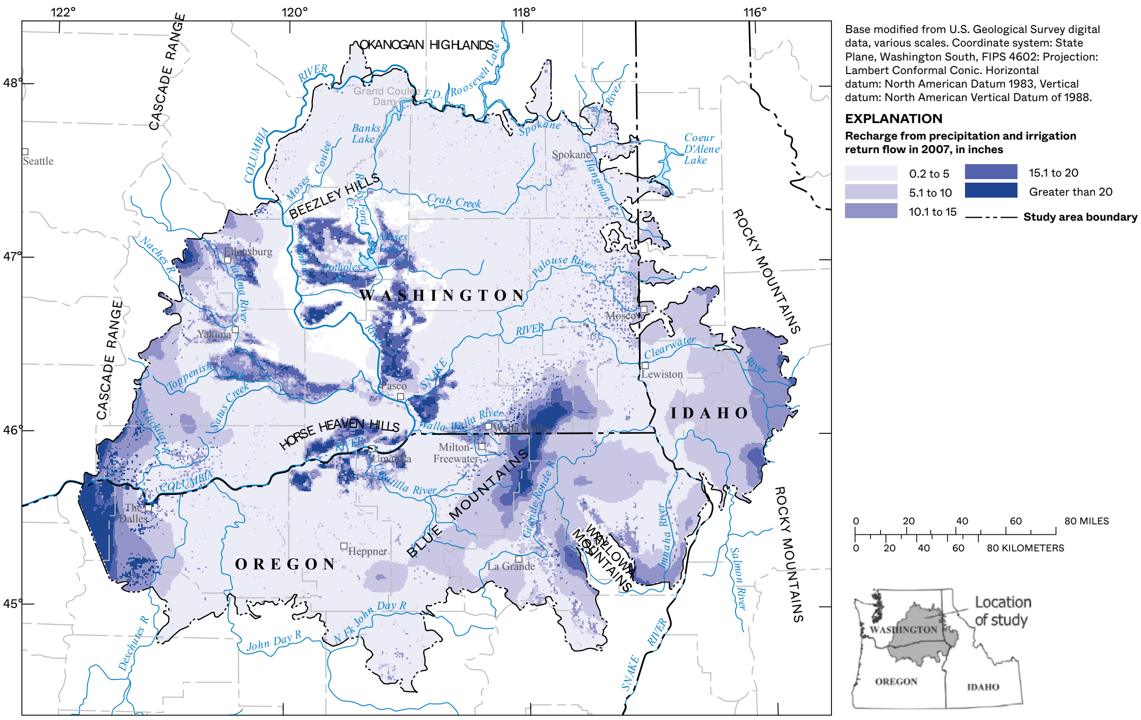

Figure 26. Map shows distribution of recharge from precipitation and irrigation return flow in the CRBG Aquifer System. Data is from 2007.[336]

As discussed in the previous section, the majority of groundwater flows laterally within interflow zones. Vertical flow is controlled by secondary features consisting predominantly of vertical joints (colonnades) and fractures in the entablature created during cooling and emplacement of the basalts and sometimes enhanced by tectonic activity that resulted in folding and faulting of the CRBG. Except for the very deep portions of the CRBG, large-scale structures can create compartmentalized flow systems with very short flow paths (which is particularly common within the Yakima Fold Belt). In deep sections of the CRBG, with limited surface water connection, compartmentalization of the aquifer system leads groundwater flow to stagnate and residence time to increase.

Based on oxygen isotopes in water, and carbon isotopes in dissolved inorganic carbon from groundwater samples from the CRBG, the age of the water ranges from less than 50 years to more than 10,000 years (Pleistocene). The oldest groundwater resides in the deep, downgradient locations, suggesting this part of the CRBG aquifer system has operated for a long timescale under natural conditions.[337] Greater age and longer groundwater residence time has been correlated with an increased degree of mineralization and higher TDS in groundwater.[338]

336. Kahle et al., "Hydrogeologic Framework," 50.

337. Kathryn B. Brown et al., "Isotopically-Depleted Late Pleistocene Groundwater in Columbia River Basalt Aquifers: Evidence for Recharge of Glacial Lake Missoula Floodwaters?," *Geophysical Research Letters* 37, no. 21 (2010): L21401, https://doi.org/10.1029/2010GL044992.

338. *See generally* Dimitri Vlassopoulos et al., "Groundwater Geochemistry of the Columbia River Basalt Group Aquifer System: Columbia Basin Groundwater Management Area of Adams, Franklin, Grant, and Lincoln Counties," (Othello, Washington: The Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties, June 2009), https://apps.ecology.wa.gov/publications/documents/0912016.pdf.

Columbia Basin Siting Evaluation

Chapter 4: Project Development Hurdles explains that the relative paucity of deep geophysical data hinders development of a GCS economy in Washington because whether and where there is a pathway to scale from Class V, experimental pilot projects to Class VI, commercial operations (under current regulations written for injection into conventional storage reservoirs) is unconfirmed. There are two major limiting constraints. First, unless a waiver is obtained, injection must occur below the lowermost USDW—meaning, into an aquifer with insufficient groundwater to supply public drinking water or with more than 10,000 mg/L TDS. Second, under current designs, the carbonated water injection technique will require a transfer of multiple water rights or a new water right permit for beneficial use of groundwater. Obtaining a water right permit will be challenging for the volume of water needed for commercial-scale operations. (While the supercritical injection technique does not need a water source, it does require water in the pore space to catalyze the reaction that converts CO_2 to a solid mineral form.) We consider the questions of injection feasibility and water availability in tandem.

Methods and Criteria

Favored sites will be appropriate for GCS and will be:

1. located in a source water aquifer with elevated TDS;
2. located in areas where a new water right has a chance of being obtained; and
3. able to supply water in sufficient quantities to meet targeted injection volumes for GCS.

For the latter two criteria, we assume that projects using the carbonated water injection technique could safely and responsibly scale using CO_2 injection volumes for a pilot project of up to 5,000 MT CO_2 total and an nth-of-a-kind project of 100,000 MT CO_2 annually, before reaching commercial-scale volumes of 1 million MT CO_2 per year. For a project aiming to sequester 5,000 MT CO_2 total, well yield can be as low as 65 gpm. For a project aiming to sequester 100,000 MT CO_2 per year, a well yield of approximately 1,400 gpm will be needed. This volume could be supplied by one or multiple wells. Each of these criteria, and the way in which they influence the feasibility of various locations, is discussed in further detail below. The Washington Columbia Basin was the area evaluated for this work because of the overlapping presence of the CRBG and state trust lands.

Distribution of Total Dissolved Solids

The groundwater chemistry database of the Washington Geological Survey (WGS) contains 1,039 groundwater sample analyses with reported measurements for TDS. An additional 462 TDS data points were added by summing the concentration of dissolved ions (cations, anions, and trace metals) to approximate TDS from samples where TDS was not directly measured. All data points were gathered from springs or wells completed in the CRBG. Summary statistics for TDS are shown in Table 6, and Figure 27 shows the distribution of wells with TDS measurements, color-coded by concentration.

There are three notable outliers where TDS exceeds 10,000 mg/L. The first is from the Rattlesnake Hills oil and gas exploration well. This well was sampled zonally at depths ranging from 1,920 to 6,010 ft on August 7, 1972. Most samples recorded a TDS of less than 1,030 mg/L. The outlying sample, which had a calculated TDS of 14,741 mg/L, was collected at an unspecified depth and had a very high calcium concentration compared to other samples from the same well: 740 mg/L compared to < 26 mg/L. This sample was also the only one that reported measurements for bicarbonate and carbonate, which were an order of magnitude higher than is typical (13,000 and 283 mg/L, respectively). Since TDS was calculated from the sum of dissolved ions for these samples, and most Rattlesnake well samples did not include bicarbonate nor carbonate measurements, we can assume that TDS in groundwater at this location likely exceeds 1,000 mg/L. However, without further detail regarding the collection and analysis of the outlying sample, confidence that TDS truly exceeds 10,000 mg/L at this location is low. Error could stem from the method of sample collection, analysis, or the way the data were subsequently recorded and reported, or if the well was not properly developed after drilling.

Table 6. Summary Statistics for TDS Values

	Measured TDS	Measured plus Calculated TDS
Count	1,039	1,501
Minimum (mg/L)	74	0
Maximum (mg/L)	1,250	14,735
Range (mg/L)	1,176	14,735
Mean (mg/L)	284	372
Standard Deviation	133	639

The left column of data shows TDS values measured in CRBG wells, and the right column shows TDS values both measured and calculated from bulk water chemistry.

The other two outlying data points (with calculated TDS of 13,167 mg/L and 12,732 mg/L) were both measured at a Hanford basalt well (DC-03) completed in the Grande Ronde, at the base of the Umtanum lava flow. Duplicate samples were collected from the production zone of the well (3575–3635 ft bgs) on March 10, 1980. These samples both had extremely high sodium and chloride concentrations, in excess of 4,300 mg/L, and a high pH. However, all other wells from the Hanford site, completed at similar depths and sampled in the same manner, have calculated TDS concentrations that are lower by an order of magnitude. That TDS concentrations in excess of 10,000 mg/L have not been measured in other nearby wells completed in the Umtanum lava flow suggests there may be an error with the DC-03 well's data. Like the Rattlesnake well, error could stem from the method of sample collection, analysis, or the way the data were subsequently recorded and reported, or if the well was not properly developed after drilling.

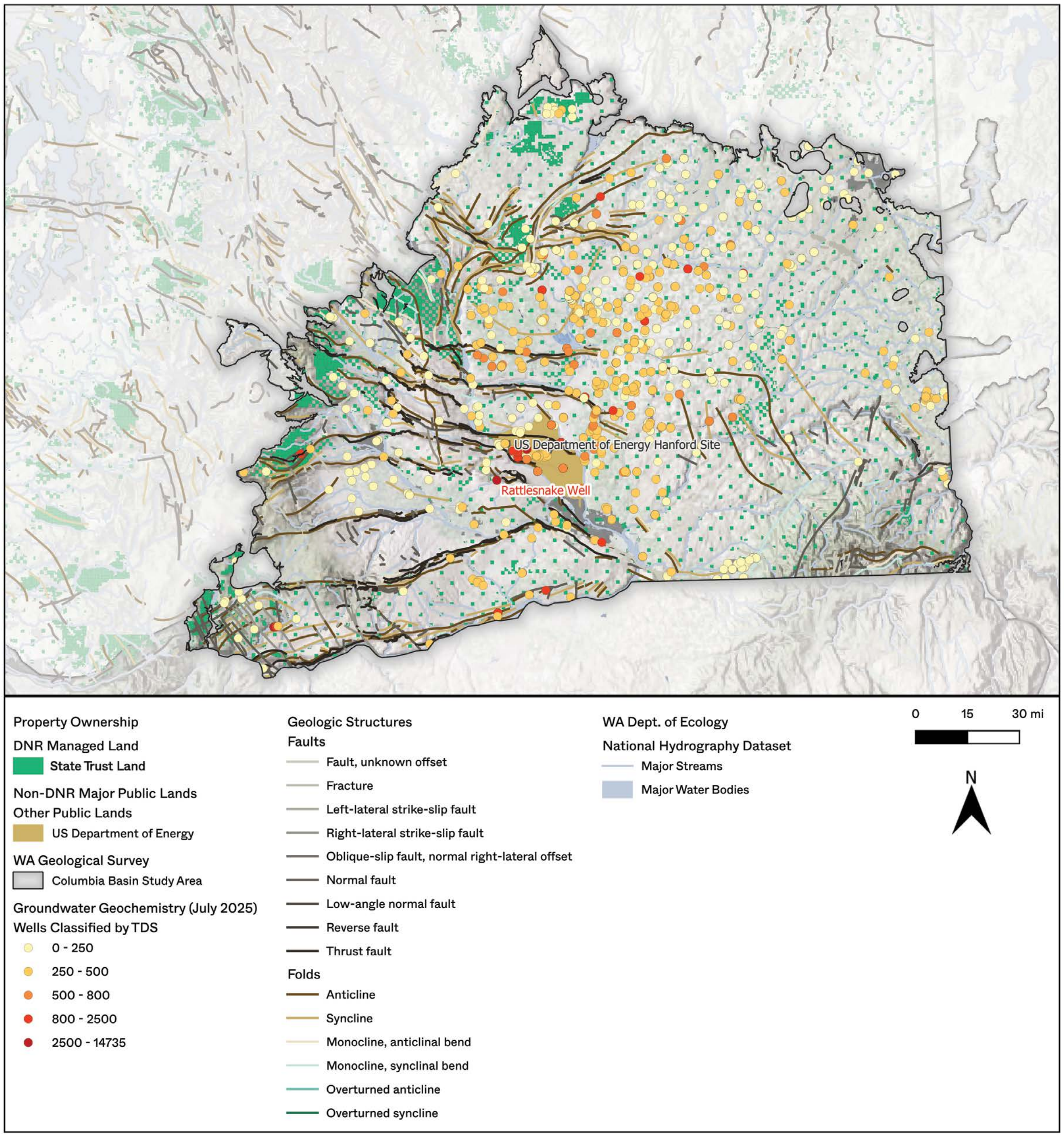

Figure 27. Map displays wells throughout the Washington Columbia Basin study area by location and classifies them by TDS.

Figure 27 demonstrates the relationship between TDS and depth. Except for the outliers discussed above, TDS does not exceed 1,631 mg/L in the wells sampled. In fact, most groundwater wells sampled in the CRBG have a TDS of less than 500 mg/L, which is the MCL for drinking water and the threshold above which plant growth can be inhibited. In the Columbia Basin, shallow wells with high TDS (>500 mg/L) are correlated to agricultural areas where irrigation has recharged the shallow basalts and built-up nitrates, phosphorus, chloride, and other ions associated with the byproducts of fertilization.

TDS also appears to exceed 500 mg/L in springs along the western side of the basin, and in wells that are greater than 2,200 ft and completed within the Grande Ronde, or both Grande Ronde and Wanapum. Spatially, most of these wells are located in the central portions of the Columbia Basin, particularly near Hanford. TDS may be elevated at the Hanford site because it is bounded by faults that impede horizontal groundwater flow, while the vantage member of the Ellensburg formation limits vertical movement of water. This results in a highly confined and compartmentalized section of the aquifer system where groundwater age and residence time is high, and water is more mineralized than in other parts of the Columbia Basin where groundwater is flowing faster.

In sum, confidence is low that TDS concentrations at sampled depths (<4500 ft) exceed 10,000 mg/L. (See Figure 28.) This finding is not surprising given that well owners and operators seek potable water and usually stop drilling when nonpotable water is reached. CO_2 injection most likely must occur below sampled depths under current UIC Class VI regulations, unless a waiver is obtainable. **Still, though the number of samples are limited, the distribution of TDS spatially and with depth suggests that further exploration should be given to the possibility of withdrawing groundwater in the Grande Ronde below 2200 ft bgs in the central portion of the basin. Water quality is poorer, and thus there is less competition for water.**

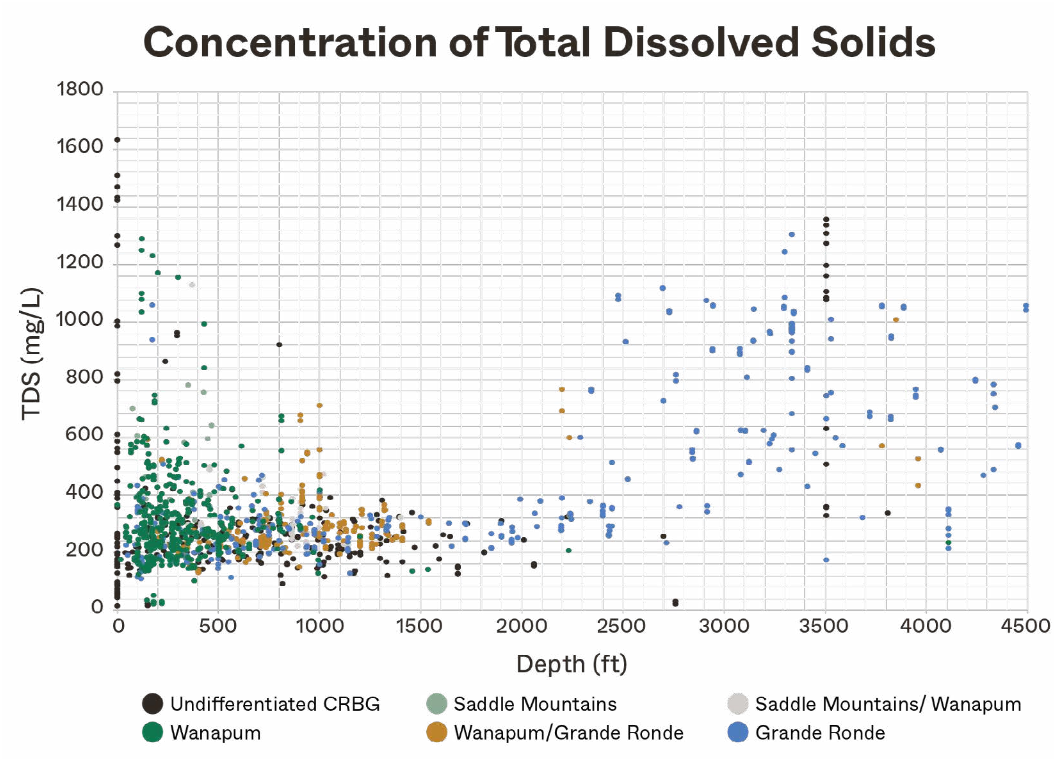

Figure 28. Scatter plot shows concentration of TDS compared to sample depth. Where depth is zero, the sample was collected at a spring. Samples are color coded by the CRBG formation from which the sample was sourced.[339]

339. Adapted from Svadlenak and Florea, *Groundwater Chemistry in the Columbia River Basalt Group*, 10.

Legal and administrative water availability

A sustainable and permit-able water supply for carbonation and injection is a critical component of the carbonated water injection technique. The Columbia Basin overlies six Water Resources Inventory Areas (WRIAs) that have different factors that limit new appropriations of groundwater. Six WRIAs are pertinent here, all of which have had water rights issued for over 100 years, and, as a result, are largely fully allocated for new surface water appropriations. An assessment was accordingly conducted on the feasibility of obtaining a water right permit to use groundwater.

Groundwater deep in the CRBG aquifer system (e.g., deeper than 2,200 ft bgs, which may contain salinity not suitable for potable or irrigation use without treatment) would be the target water source for a GCS project utilizing the carbonated water injection technique and needing a new water right.

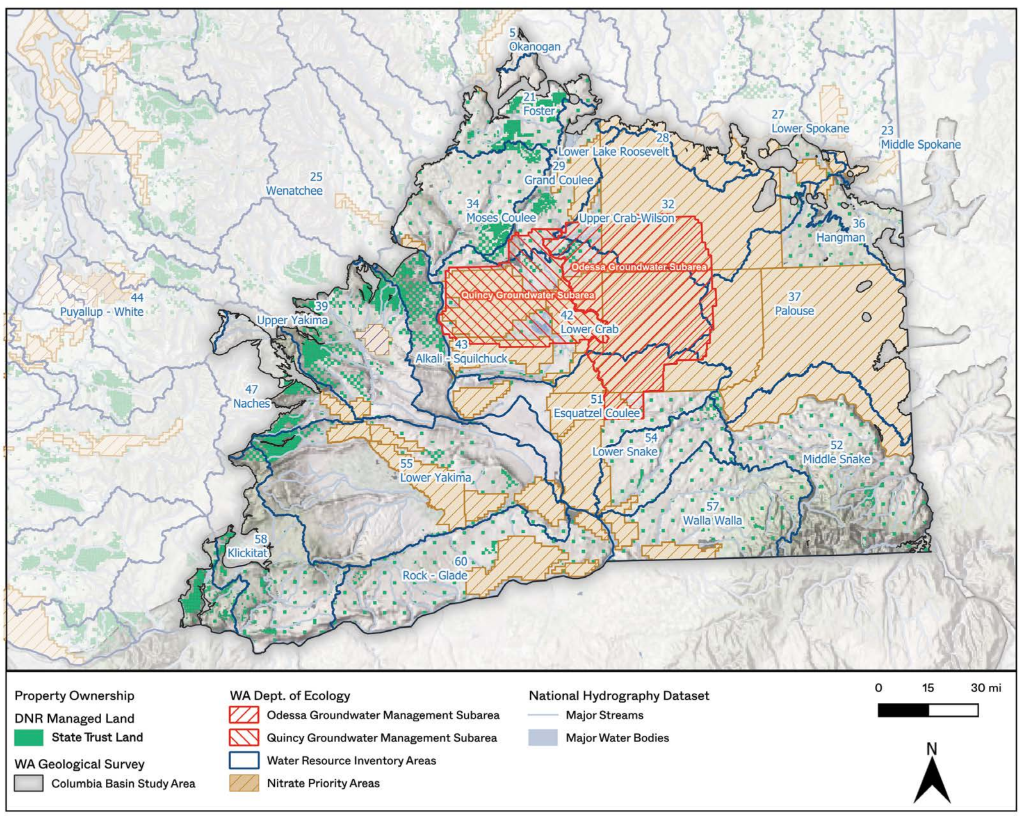

Figure 29. Map shows groundwater management subareas, nitrate priority areas, and WRIAs within the Washington Columbia Basin study area.

Areas with known declining groundwater levels and other water resource challenges where a new water right is unlikely to be obtained were eliminated. The Quincy and Odessa Groundwater Management Subareas and the Walla Walla subbasin were excluded, as these are locations where declining groundwater levels have been documented within the CRBG.

The Yakima subbasin was also de-prioritized, as drought and declining surface water supplies have put increasing stress on groundwater resources in recent years. Areas with known nitrate contamination (a result of irrigation recharge) were also de-prioritized, as these are areas where water resources are under significant scrutiny. While the presence of nitrates is unlikely to impact GCS projects considering their much deeper depth, Ecology may more strictly scrutinize injection into or withdrawal from areas where groundwater supply is known to be adversely impacted, potentially slowing time to deployment. (See Figure 29.)

Areas with limited groundwater development and prior appropriation were prioritized for further exploration. Figure 30 shows areas where well density is high and groundwater points of use are common, to identify regions with the greatest degree of groundwater development. These areas were excluded from further exploration because they would mean a high degree of competition for a new water right and a greater potential for interference. While this approach limits horizontal competition over water resources, vertical competition and groundwater connectivity should also be considered, and is discussed in subsequent sections.

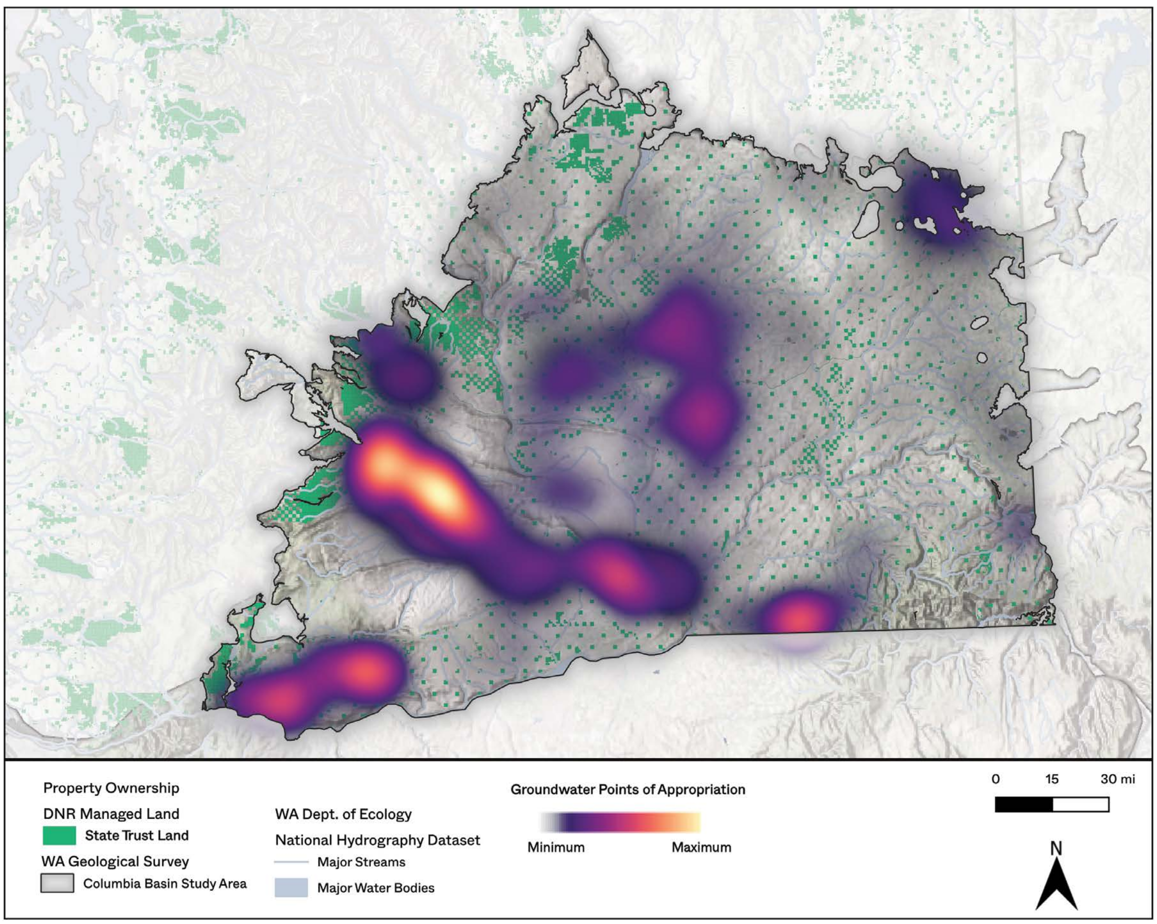

Figure 30. Heat map shows water wells and groundwater points of diversion within the Columbia Basin study area. Brighter colors (white, orange) indicate a higher well density and more groundwater withdrawal, while cooler, darker colors (purple, black) indicate a lower well density and less groundwater withdrawal. Areas without shading have the lowest density of wells and least withdrawal points.

Given the long history of groundwater pumping for crop irrigation, municipal, and domestic water supply in the Columbia Basin, a new groundwater right may be challenging to acquire. A new right will need to be developed at a location and depth such that supply to existing groundwater users is not impaired. The rate and volume of supply will be set by Ecology to ensure the long-term health and sustainability of the pumped aquifer. **A new source that is away from other groundwater users and taps poor quality or very deep water will have the least current and future competition for a new water right.**

Hydrogeologic Feasibility

The CRBG is often modeled as continuous, laterally extensive, basalt sheet flows that are vertically stacked upon each other. In reality, its flows are heterogeneous with thicknesses and textures that vary based upon the land cover and topography at the time of eruption and emplacement. CRBG flows are further interrupted by faulting and folding, particularly in the Yakima Fold Belt, north and west of the Columbia River. These faults can act as barriers or

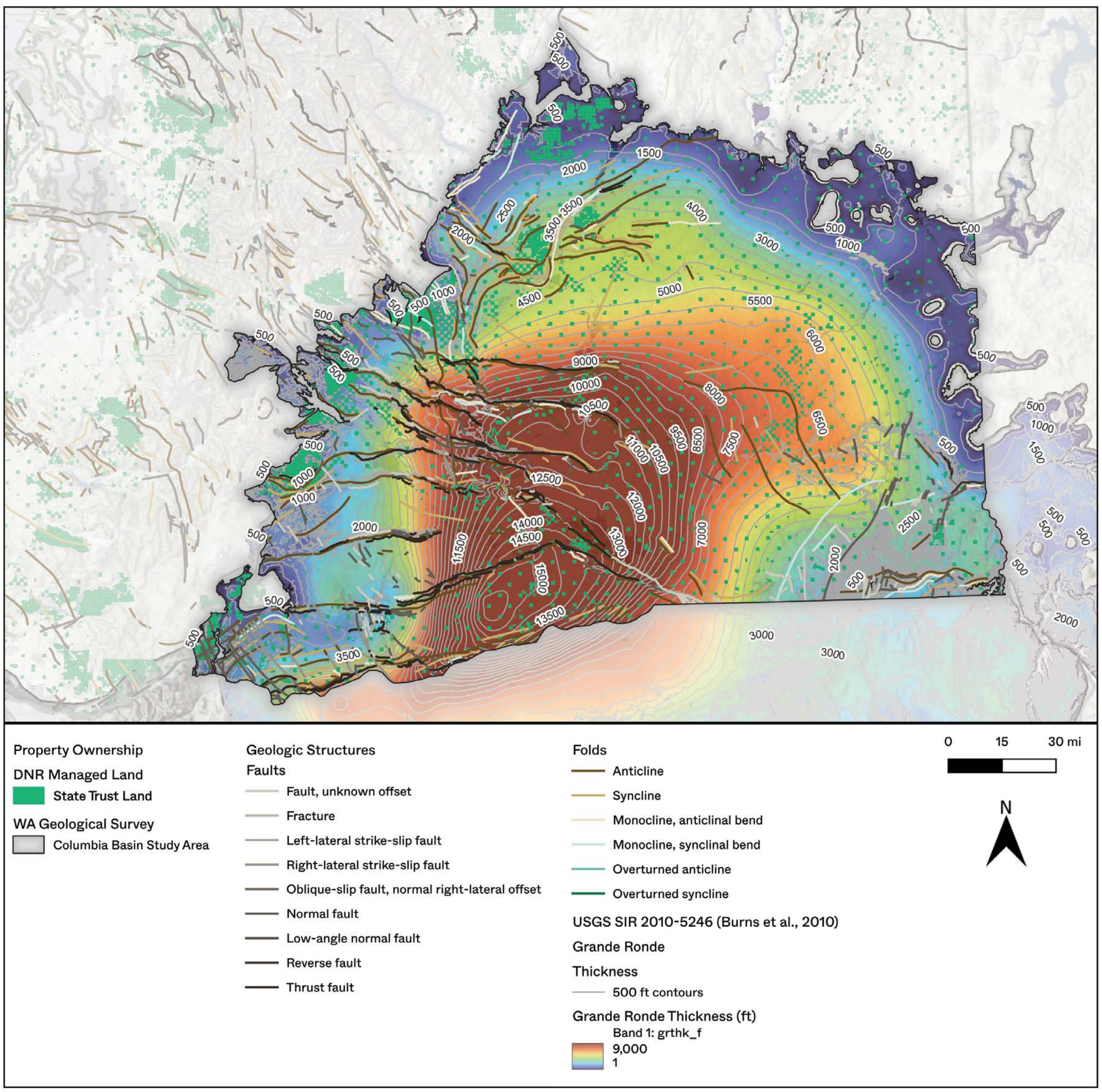

Figure 31. Map shows the thickness of the Grande Ronde Formation and the location of geologic structures.

conduits to groundwater flow, depending on their age. Actively moving faults tend to act as pathways, while older stationary faults are fully annealed and act as barriers to groundwater flow. Understanding the location of faulting and folding within the basin is critical to understanding fluid flow in potential GCS sites. Older faults and anticlines may act as structural traps for injected CO_2, boosting favorability for further exploration.

In addition to confining structures, a thick package of CRBG flows is necessary to ensure that (1) injected CO_2 does not migrate into another geologic formation and (2) that water pumped from a well completed in the basalts is not inducing flow or cross connection from a neighboring geologic unit. The Saddle Mountains Basalt is the youngest, shallowest, and thinnest basalt formation within the CRBG. As a result, groundwater from the Saddle Mountains has already been heavily developed throughout much of the Columbia Basin. **The underlying Wanapum and Grande Ronde formations are better targets for injection and as water sources with minimal competition/prior development. The Grande Ronde thins along the basin margins, and the Wanapum is not present along the northwest margin, which shifts the evaluation area for a GCS project and water supply well closer to the center of the basin.** (See Figure 31.)

The USGS modeled the effective mean hydraulic conductivity (the ease with which groundwater can flow through the aquifer) for each basalt formation in 2014 and observed that the Saddle Mountains has the highest average hydraulic conductivity at 14.1 ft/d, followed by the Wanapum at 12.6 ft/d, and Grande Ronde at 10.5 ft/d. However, these values can vary widely depending on the thickness and nature of interflow zones (i.e., vesicular or brecciated), proximity to geologic structures, and continuity of the lava flow. While the Grande Ronde tends to have the lowest hydraulic conductivity, well yields can still exceed 2,000 gpm in some locations. Each of these three formations could produce well yields sufficient for an nth-of-a-kind project seeking to sequester 100,000 MT CO_2 annually.

Results

Three areas for further exploration considering both the hydrogeologic conditions for safe and permanent GCS and a water supply well for which a new water right for groundwater may be obtainable are shown on Figure 35 (in Chapter 9: Siting Prioritization), and are referred to as the Canoe Ridge/Horse Heaven Hills Area of Interest (AOI), Palouse Slope AOI, and Rattlesnake Hills AOI. These AOIs are located in areas where DNR manages a concentration of state trust lands, groundwater levels appear stable, aquifers are minimally developed, and a deep well control point is nearby (from oil and gas or GCS exploration and testing). Sites are centrally located within the basin and overlie a thick package of Grande Ronde basalt. Both the Canoe Ridge/Horse Heaven Hills and Rattlesnake Hills AOIs are faulted and folded, and they are promising settings for structural traps and isolated pockets of mineralized (high TDS) groundwater. The Palouse Slope is less structurally deformed, which allows for greater extrapolation between data points and poses an easier setting to explore the deeper layers of the Grande Ronde.

Canoe Ridge/Horse Heaven Hills

The first AOI is located southwest of the Tri-Cities and is bounded by the Columbia River to the south and Horse Heaven Hills to the north. (See Figure 32.) This is the largest AOI and includes the highest number of state trust lands. There is some irrigated cropland within the AOI, though most of the land cover is dryland wheat farming or rangeland. Wells in the area are primarily for irrigation, stock water, or domestic use.

Wells with TDS measurements show a range of concentrations from 151 mg/L to 1309 mg/L. The highest TDS values were calculated from water chemistry data collected from the 3025-foot deep 100 Circles #1 natural gas storage exploration well.[340] East of the 100 Circles well, the K2H gas storage characterization well was completed to 3851 ft bgs, but TDS only measured 891 mg/L. While well above the drinking water MCL of 500 mg/L, these values are still far below the 10,000 mg/L threshold stated for operation of a Class VI well.

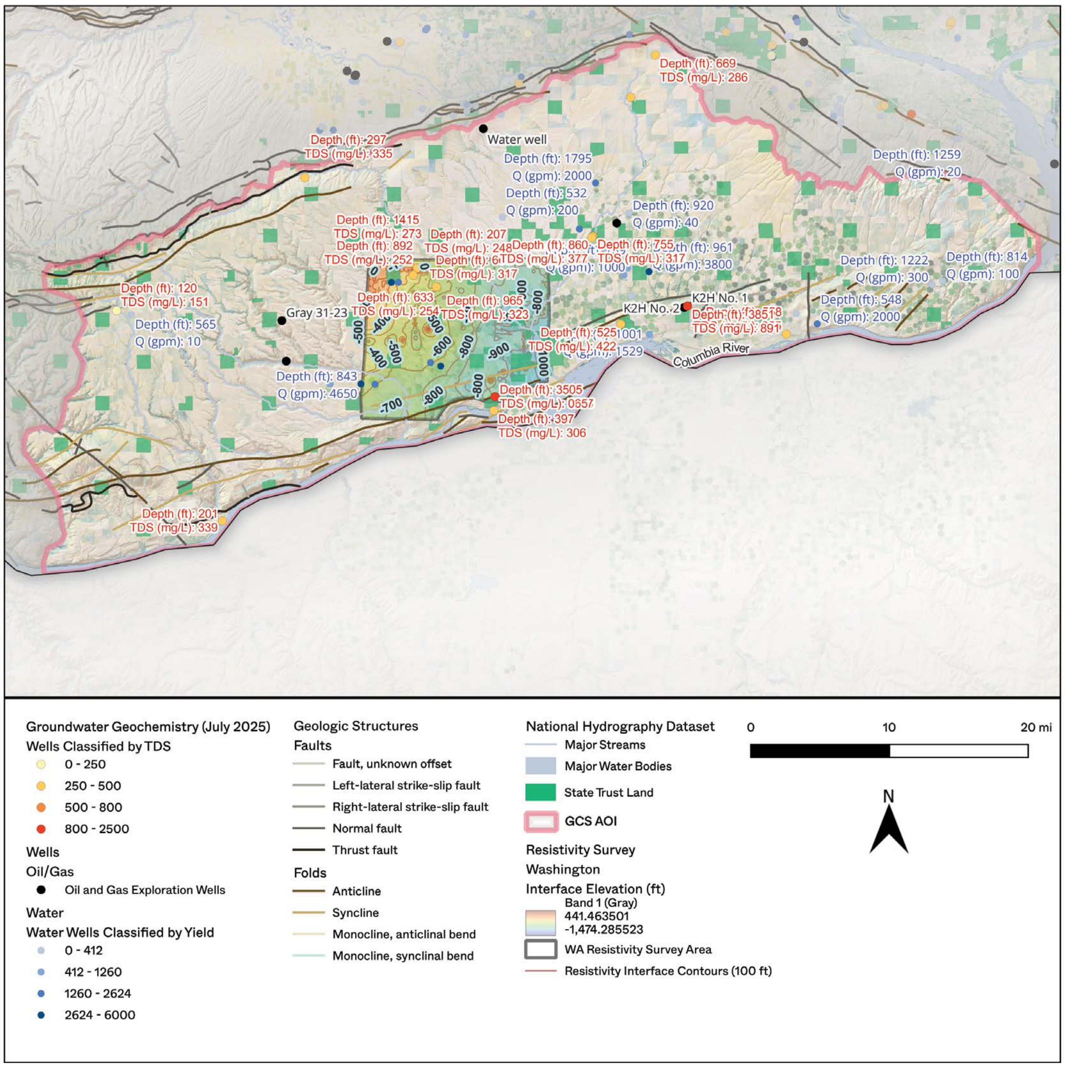

Figure 32. Map shows the Canoe Ridge/Horse Heaven Hills AOI and depicts oil and gas well locations (black) and water wells classified by yield and TDS. The area and elevation of the resistivity transition from high to low observed by the 2024 AEM Survey is shown in the central portion of the AOI.

340. Steve P. Reidel et al., "Potential for Natural Gas Storage in Deep Basalt Formations at Canoe Ridge, Washington State: A Hydrogeologic Assessment," ed. Pacific Northwest National Laboratory (USDOE, 2005), https://doi.org/10.2172/966666.

The Carbon Containment Lab collected resistivity data within the Canoe Ridge/Horse Heaven Hills AOI during the 2024 AEM Survey.[341] (See Figure 23.) This effort identified a drop in resistivity between roughly 1,000 and 2,000 ft bgs (elevations of roughly -400 to -1100 ft below mean sea level [msl]). While this change could be indicative of a saline water boundary, the limited water quality from deep wells within the AOI may limit the ability to ground-truth this observation. Another possible explanation for the resistivity drop is the presence of a fine-grained interbed with high clay content, similar to the Selah member of the Ellensburg formation. An interbed identified as the Selah on a driller's log was detected by the 2024 AEM Survey on the Oregon side of the river, but at a shallower depth than the resistivity drop at the bottom reach of the Survey. Sedimentary interbeds occur at all levels within the CRBG, and the deep resistivity drop somewhat follows the dip of the Grande Ronde as modeled by the USGS within the AOI. A sedimentary interbed would likely follow the same trend. Further well testing and water quality sampling below the depth of the resistivity drop is needed to confirm whether the interface is due to a change in water quality or lithology.

Groundwater is generally less developed in this region than in other parts of the basin. This lack of development improves the likelihood of developing a new water right in an underutilized portion of the basin. Considering that the groundwater source to be developed would be from deeper parts of the CRBG, this source could possibly have little impact on existing groundwater wells in the area. If a deeper well is tested (e.g., pumped at a high rate for an extended period of time), it would help to evaluate the hydraulic connectivity to existing sources. Well yield information gathered from the WGS geothermal well database indicates that well yields within the AOI can exceed 2,000 gpm below 892 ft. These yields are high enough to supply a GCS project with water for carbonation from a single well. (See Figure 32.)

Palouse Slope

The next AOI is located along the Palouse slope, northeast of the Tri-Cities. State trust lands are distributed throughout this AOI, and land use is generally irrigated cropland or dry farming. Similar to the Canoe Ridge/Horse Heaven Hills AOI, wells in the area are primarily used for irrigation, stock water, or domestic supply.

The highest TDS measurement recorded in the WGS groundwater chemistry database is 549 mg/L, at a 940-foot deep well in the northeast corner of the AOI. Where groundwater chemistry data are available, TDS appears relatively low compared to other AOI's. However, this location does not have as many deep water wells or oil and gas exploration wells as the Canoe Ridge/Horse Heaven Hills AOI. The only oil and gas exploration well within the AOI is the Darcell Western No. 1 well, which was drilled to 8,556 ft, then plugged and abandoned.

This AOI has the least amount of groundwater development, which may increase the likelihood of developing a new water right in an underutilized portion of the basin. Well yield information gathered from the WGS geothermal well database is scarce. Of the wells with yield information within the AOI, most wells are producing less than 100 gpm. However, there are two exceptions in the western half of the AOI. One well is 1,309 ft deep and produces 3,500 gpm,

341. Oristaglio, "Expert Workshop."

and the other well is located near the northwest corner of the AOI and produces 2,000 gpm from a depth of 1,211 ft. Because well yield can be influenced by well design, construction, and pump capacity, this site should be further investigated to determine whether the range in yields is due to demand for a particular well use (e.g., low yield for domestic and stock water vs. high yield for irrigation), well design, or variable characteristics of the aquifer. Even if a single well cannot produce the minimum discharge set for this analysis of 1,400 gpm, a well pair or well field may be able to meet the desired discharge when pumping together at a lower rate. (See Figure 33.)

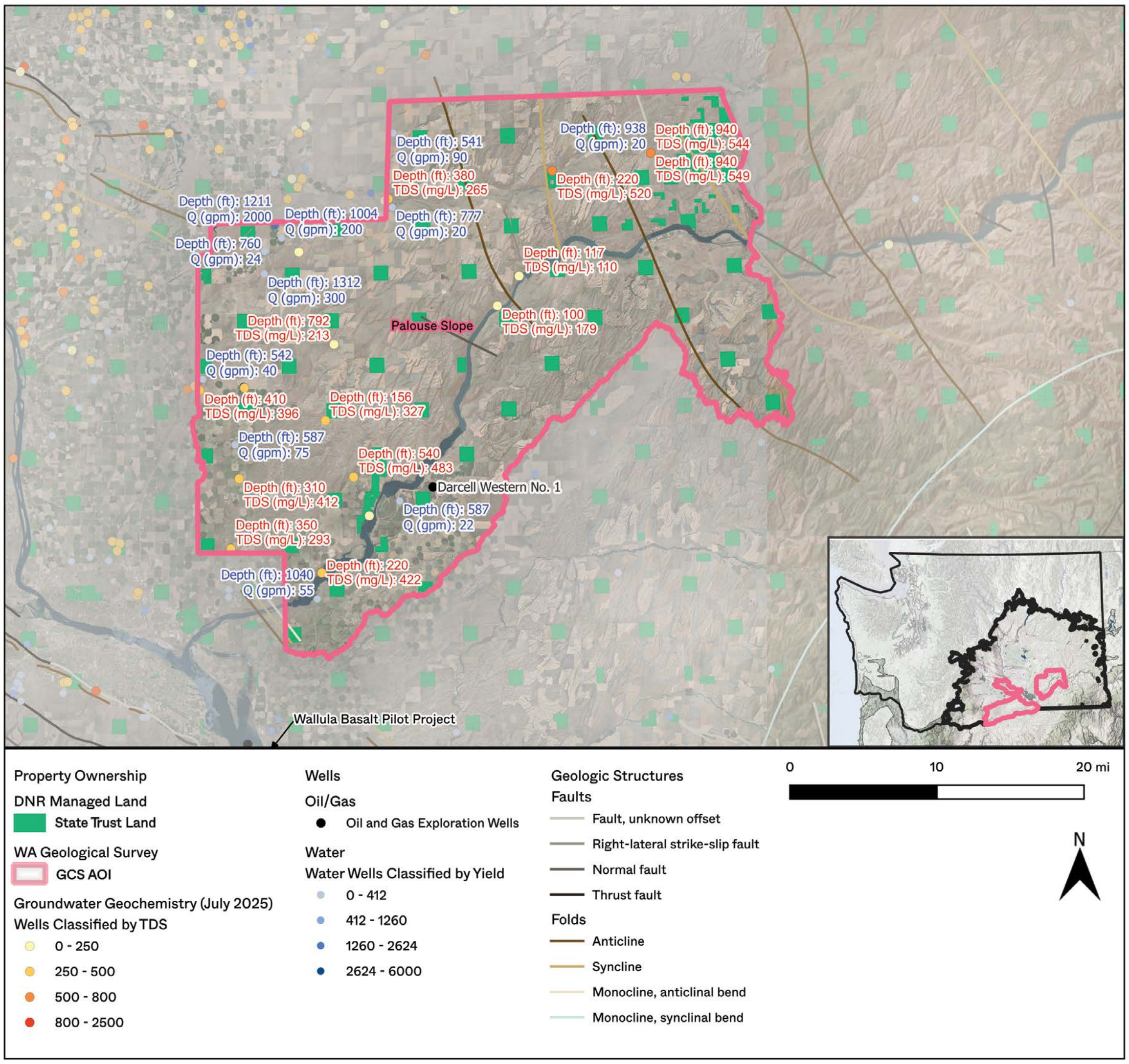

Figure 33. Map shows the Palouse Slope AOI and depicts oil and gas well locations (black) and water wells classified by yield and TDS.

The southwest extent of this AOI is in close proximity to the Wallula Basalt Pilot Project. While not within the AOI, data from this site can be used to inform future more detailed studies on the Palouse Slope, which appears to have undergone less faulting and folding than areas west of the Columbia River and which may be more easily explored as data can be extrapolated across greater distances. Furthermore, the CRBG flows are dipping southwest and are close to their thickest point in this location. While structural traps are unlikely in this area, the thick package of layered lava flows may contain multiple interflow zones that could be utilized for GCS and/or a water supply.

Rattlesnake Hills

Rattlesnake Hills is located north of the Horse Heaven Hills and south of the Hanford Reservation, and it has the highest percentage of state trust lands by acreage. Like the other AOIs, wells in the area are primarily used for irrigation, stock water, or, rarely, domestic use.

Minimal measurements of TDS exist within this AOI. Of these, one is from a spring where TDS was measured at 160 mg/L, and the other is from a 1,201 ft deep well where TDS was measured at 202 mg/L. However, the Rattlesnake oil and gas exploration well (located near the center of the AOI) has a calculated TDS between 622 and 1,028 mg/L (depending on the sample collection depth and excluding an anomalous measurement that exceeded 14,000 mg/L). Sample depths ranged from 1,940 to 6,010 ft bgs, which suggests TDS may exceed the drinking water MCL below 1,940 feet. If the CRBG beneath Rattlesnake Hills is similarly compartmentalized to the Hanford site, then groundwater may have increasingly elevated TDS with increasing depth, similar to Hanford.[342]

While minimal groundwater development has occurred along Rattlesnake Hills, groundwater has been developed extensively lower in the valley, south of the AOI. This area also falls within the Yakima River Basin, which has been experiencing drought since 2023 that has put a strain on both surface water and groundwater resources, and, as such, may be the most difficult area in which to obtain a new groundwater right even at depth.

Well yield information gathered from the WGS geothermal well database indicates that well yields within the AOI can exceed 1,450 gpm below 886 ft in the northern half of the AOI. In the southern half of the AOI, well yields generally exceed 500 gpm. These yields appear sufficient to supply a GCS project with water for carbonation and injection from either a single well or well pair. (See Figure 34.)

342. Several other oil and gas exploration wells are located within the Rattlesnake AOI, but these wells appear to not have water quality data associated with them. These are the Robert No. 1, Anderson 11-5, Horseshoe No.1, and Prosser-Grandview wells. Lithologic and other data from these wells could be useful to future evaluations of GCS feasibility in this area.

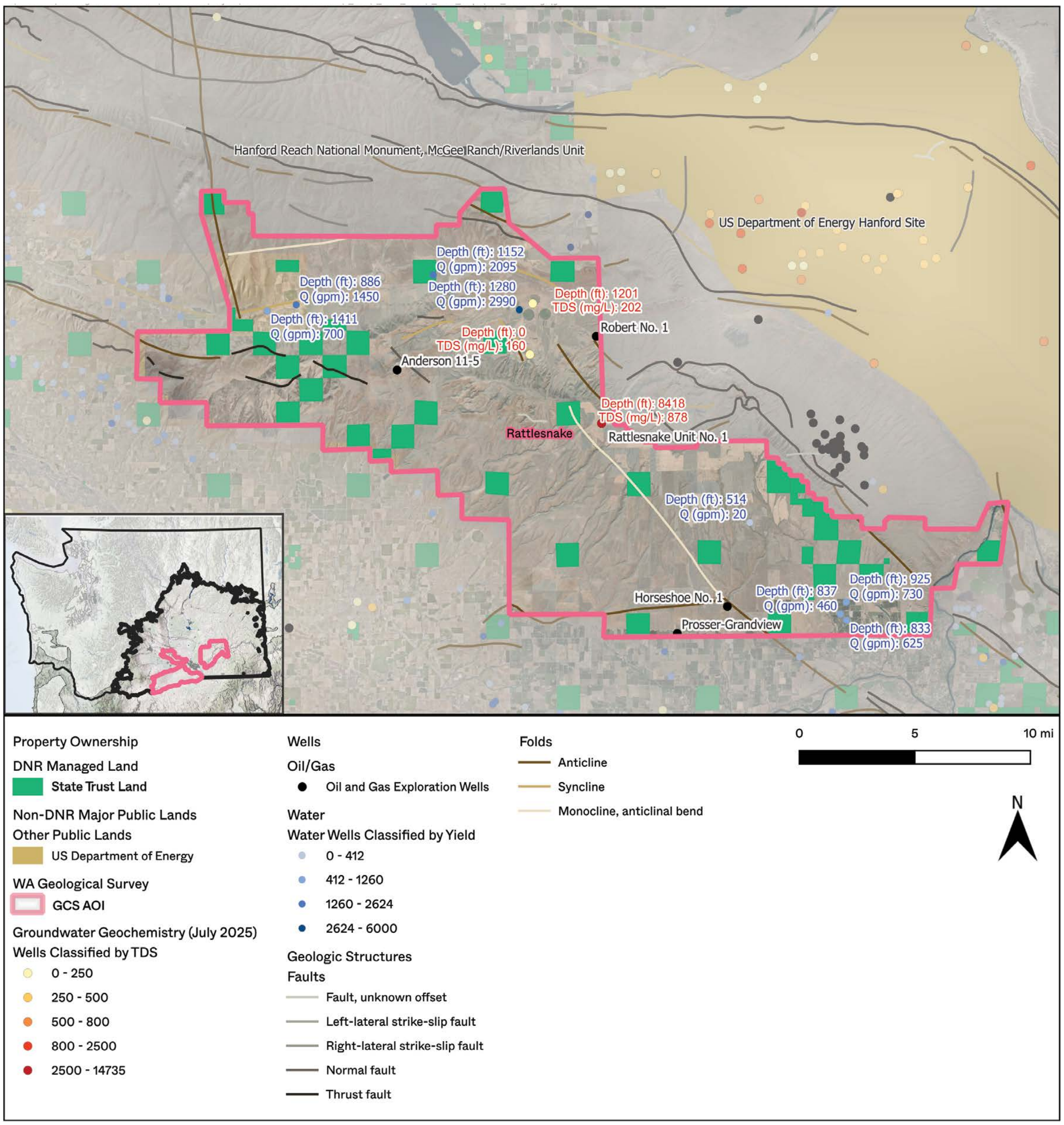

Figure 34. Map shows the Rattlesnake Hills AOI and depicts oil and gas well locations (black) and water wells classified by yield and TDS.

Conclusions and Recommendations

The three AOIs identified reflect the areas that a desktop survey indicates are most promising for a GCS project wanting to avoid injecting into potable water and utilizing a new groundwater source. However, each of these areas requires further exploration and more detailed study, especially before a deep test well is drilled.

Sources of Uncertainty

A significant limiting factor to this analysis was the scarcity of data below depths of 1,000 ft. This poses a challenge to understanding groundwater quality, permeability, and hydraulic conductivity within CRBG aquifers at depth. The heterogeneous nature of the CRBG also makes it difficult to extrapolate across distances using the limited existing data points. Furthermore, this analysis was targeting previously undeveloped portions of the CRBG aquifer system, which inherently have fewer wells and are less studied. While most information on the Columbia Basin is publicly available through state and federal agencies or peer-reviewed literature, data associated with deep oil and gas wells is often proprietary or otherwise not publicly available. The challenge of data scarcity is likely to persist without significant investment in local and/or site-specific exploration (e.g., detailed mapping, exploration well drilling, yield and water quality testing, borehole geophysics, and regional-scale geophysical data collection) led by DNR with support of a P3.

As noted in Chapter 4: Project Development Hurdles, this paucity of data also calls into question the ability of GCS to scale under current regulations. The regulations governing UIC Class VI wells were written for, and are best suited to, traditional sedimentary basins where water at depth is highly saline. Connate waters in the CRBG are quite fresh, with TDS concentrations well below 10,000 mg/L, and often less than 1,000 mg/L. Despite this, it is unlikely that groundwater deeper than a few thousand feet beneath ground surface will ever be developed for drinking or irrigation use considering the costs of drilling to this depth and treatment to drinking water standards.

Lastly, uncertainty remains regarding water right availability for deeper, poor-quality water within the three AOIs. Groundwater levels in the Saddle Mountains and Wanapum are declining in some locations, and groundwater resources are overallocated. As such, a new groundwater right will not be possible in these shallower locations/formations. However, the Grande Ronde is significantly less developed and has historically been more stable, so a new groundwater right may be possible. Ultimately, the only way to know whether a water right permit (most likely for brackish groundwater or water that is so deep that no senior water right holder for that body of water exists) is by developing test water wells and opening a dialogue with Ecology.

Recommendations for Further Exploration

Prior to drilling a test well or implementing a pilot project, a general geologic conceptual model for groundwater flow and availability in each AOI should be completed. Further exploration by various P3 partners, as and when applicable, is also needed and could include the following.

- Review well drilling logs from Ecology's water well report database for additional hydrogeologic information. This review could include gathering measurements of well yield and static water level and lithologic descriptions to aid in geologic cross-section development and subsurface mapping of CRBG interflow zones. Consultation with other researchers who have extensive geologic and hydrogeologic CRBG experience in each AOI should be completed.

- Correlate well completion zones to a specific interflow zone within CRBG aquifer systems. This work could be done by comparing lithologic descriptions between wells or comparing elevations of well production zones to USGS models of the top of the Wanapum and Grande Ronde formations.

- Correlate well yields and water quality with formations within the CRBG and identify a target production zone for a new water supply well based on highest yields.

- If possible, complete aquifer testing at select existing wells that are within the target formation to determine the transmissivity and sustainable yield that are anticipated within the target aquifer(s). A water quality sample could be collected for an accurate measurement of TDS.

- Collect geophysical data. This work could include data from AEM surveys, gravity data, or seismic data, as well as downhole geophysics. Geophysical data may offer an easier way to explore large areas of the basin for both suitable GCS sites and to identify areas where high TDS water may be present. Geophysical data should be groundtruthed using well and water quality data.

- GCS project developers needing a water right permit should engage with Ecology. Early engagement will help to identify the most appropriate permitting approach and areas where a new water right application is most likely to be approved.

- Conduct a geochemical compatibility analysis to ensure that injecting carbonated water will not adversely react with native groundwater nor aquifer rock. Adverse reactions could include excessive scale formation (clogging) or a failure to precipitate carbonate minerals. Ideally, this evaluation would utilize data acquired from a test well, but an initial study could be completed using existing data.

Recommendations for Alternative Water Sources

Should a new year-round groundwater right prove infeasible, alternative sources could be considered. First, if a surface or groundwater right permit can only be acquired seasonally but can be acquired for double the volume needed for carbonation, half of the water produced during the permitted season could be used for GCS, and the other half could be stored using ASR. During the off-season, water from the ASR well could be recovered and utilized for carbonation and injection, allowing GCS year-round.

Wastewater also could serve as another potential water supply. This potential source may provide a co-benefit of providing a discharge method for water that would otherwise need extensive treatment or go unused. The challenges will be in finding a wastewater source that is close to an injection site, ensuring the wastewater quality is suitable for carbonation and injection, and protecting against contamination to the aquifer system beyond the injection zone.

KEY TAKEAWAYS:

- Confidence is low that TDS concentrations at sampled depths exceed 10,000 mg/L. CO_2 injection most likely must occur below sampled depths (<4,500 ft) under current UIC Class VI regulations, unless a waiver is obtainable.
- Groundwater deep in the CRBG aquifer system (e.g., deeper than 2,200 ft bgs), which may contain salinity ill-suited for potable or irrigation use without treatment would be the target water source for a GCS project utilizing the carbonated water injection technique and needing a new water right.
- When pursuing a new water right, it is best to engage with Ecology early in the process.
- The Grande Ronde and Wanapum Basalt formations are a better target for injection and as a water source with minimal competition/prior development of water than the Saddle Mountains Basalts. These two formations are thickest in the center of the Columbia Basin, so the central basin is preferred for a GCS project and water supply well.
- Three areas for further exploration considering both the hydrogeologic conditions for safe and permanent GCS, and a water supply well for which a new water right for groundwater may be obtainable, are the Canoe Ridge/ Horse Heaven Hills AOI, Palouse Slope AOI, and Rattlesnake Hills AOI. Each AOI contains the Grande Ronde and Wanapum Basalt formations.
    - The Carbon Containment Lab collected resistivity data within the Canoe Ridge/Horse Heaven Hills AOI during the 2024 AEM Survey. A drop in resistivity between roughly 1,000 and 2,000 ft bgs (elevations of roughly -400 to -1100 ft below msl) was observed. This change could be indicative of a saline water boundary or the presence of a fine-grained interbed like the Selah member of the Ellensburg formation.
    - Alternative water sources, such as use of ASR with a seasonal water supply and wastewater, should be considered by GCS project developers desiring to use the carbonated water injection technique at commercial scale.

9. Siting Prioritization

Siting Prioritization

DNR manages 4,658 parcels of state trust lands within the CRBG, totaling 1,420,800 acres. Properly siting GCS among these parcels requires identifying which satisfy several criteria, the two most critical of which are that (1) the parcel overlays geologic and hydrogeologic conditions deemed regulatorily safe and practically conducive for CO_2 injection and mineralization, and (2) deployment there must not violate Tribal Treaty rights and must seek to avoid adverse impacts to archeological, cultural, and historic resources. These factors, and others, should be considered when developing a statewide strategy for siting GCS.

Chapter 4: Project Development Hurdles describes the federal and state regulations governing the injection of CO_2. We also encourage reading the preceding chapters of this section, starting with **Chapter 5: Siting Criteria** before reading this conclusion.

Geologic and Hydrogeologic Review

As discussed in detail in Chapter 7: Geologic Setting and Chapter 8: Hydrogeologic Setting, a desktop review of the CRBG's geology and hydrogeology indicates the Grande Ronde and Wanapum Basalt formations offer the greatest potential for safe and permanent GCS. These formations are thick, present at depths suitable for either injection technique, and contain permeable interflows that are likely capable of both receiving injected CO_2 and supplying water for carbonation and injection at the scales evaluated. In some areas, faulting and folding of the CRBG has created compartmentalization that isolates permeable interflows and creates an ideal trap for injected and sequestered carbon.

Three regions contain these formations and confining layers or geologic structures that can act as caprock, preventing the vertical migration of CO_2:

- Canoe Ridge/Horse Heaven Hills;
- Palouse Slope; and
- Rattlesnake Hills.

In total, 339 parcels of state trust lands, representing 127,588 acres, are situated within these three AOIs. (See Table 7; Figure 35.) Their potential to host GCS should be further explored in a statewide GCS siting strategy.

Table 7. Acreage of State Trust Land within Each AOI

AOI	Parcel Count	DNR-Managed Surface Area (acres)	Area of AOI (acres)	DNR-managed Coverage (%)
Canoe Ridge/Horse Heaven Hills	170	62,688	861,627	7
Palouse Slope	123	42,948	594,537	7
Rattlesnake Hills	46	21,952	194,191	11

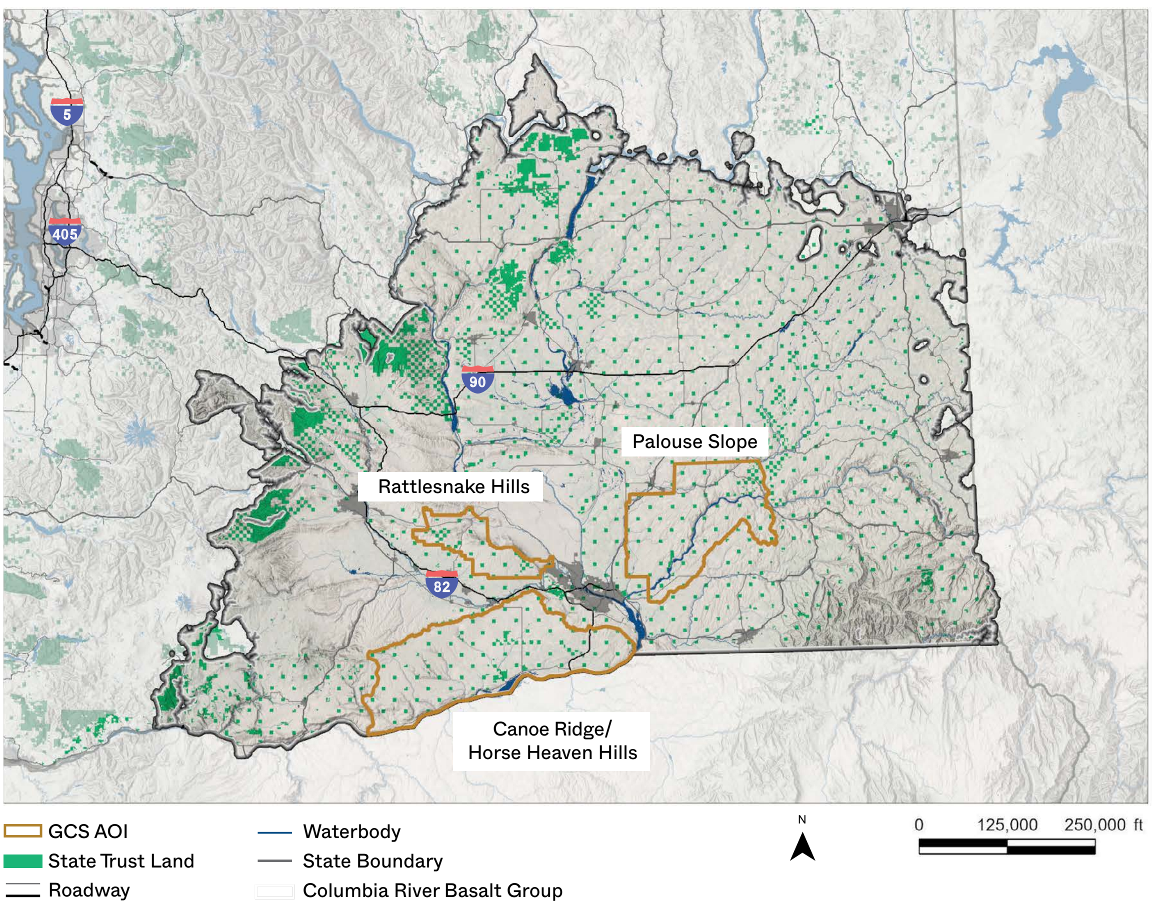

Figure 35. Map displays major roadways and highlights for further GCS exploration three AOIs within the CRBG: Canoe Ridge/Horse Heaven Hills, Palouse Slope, and Rattlesnake Hills.

While none of these three AOIs has credible water well data with TDS concentrations exceeding the 10,000 mg/L threshold presently required for operation of a UIC Class VI well, it is plausible that groundwaters in deeper sections (e.g., 600 m [≈ 2,000 ft] or deeper) might have higher TDS concentrations. Within the Canoe Ridge/Horse Heaven Hills AOI, the 2024 AEM Survey detected lower resistivity between roughly 1,000 and 2,000 ft bgs (elevations of roughly -400 to -1100 ft below msl), which is suggestive of either the presence of a saline water boundary with high TDS concentrations or a fine-grained interbed of unknown transmissivity.

GCS project developers utilizing the carbonated water injection technique could consider the Canoe Ridge/Horse Heaven Hills AOI and Palouse Slope AOI, both of which a greater chance of obtaining a water right permit for use of groundwater than the Rattlesnake Hills AOI, though conversations with Ecology would be required no matter the AOI. The target source should be groundwater deep in the CRBG aquifer system (e.g., >2,200 ft bgs, which may contain salinity not suitable for potable or irrigation use without treatment) or alternative sources for which no water right is required. If a water right permit is obtained, potential yields would support injecting 100,000 MT CO_2 per year, offering a pathway to scale GCS from pilot project injection volumes of 1,000 MT CO_2 total. (Injection volumes larger than 100,000 MT CO_2 per year were not considered.)

Tribal Treaty Rights and Cultural Resource Assessment

A focused background literature review was conducted to identify previously recorded cultural resources located on state trust lands within each AOI. The review was performed using the Washington Information System for Architectural and Archaeological Records Data (WISAARD), as well as Tribal websites.

According to the Department of Archaeology and Historic Preservation's (DAHP's) predictive model, all three AOIs, at various places, contain low to very high risk for containing archaeological resources. Variability in risk across the AOIs is largely due to topography, proximity to water, soils, and other environmental factors. In brief:

- The Canoe Ridge/Horse Heaven Hills AOI has higher risk for archaeological resources along ridgelines, the Columbia River, and its tributaries. (See Figure 36.)

- The Palouse Slope AOI has higher risk located along the Snake River and its tributaries, as well as ridgelines. (See Figure 37.)

- The Rattlesnake Hills AOI has higher risk located along ridgelines, streams, and tributaries to the Yakima River. (See Figure 38.)

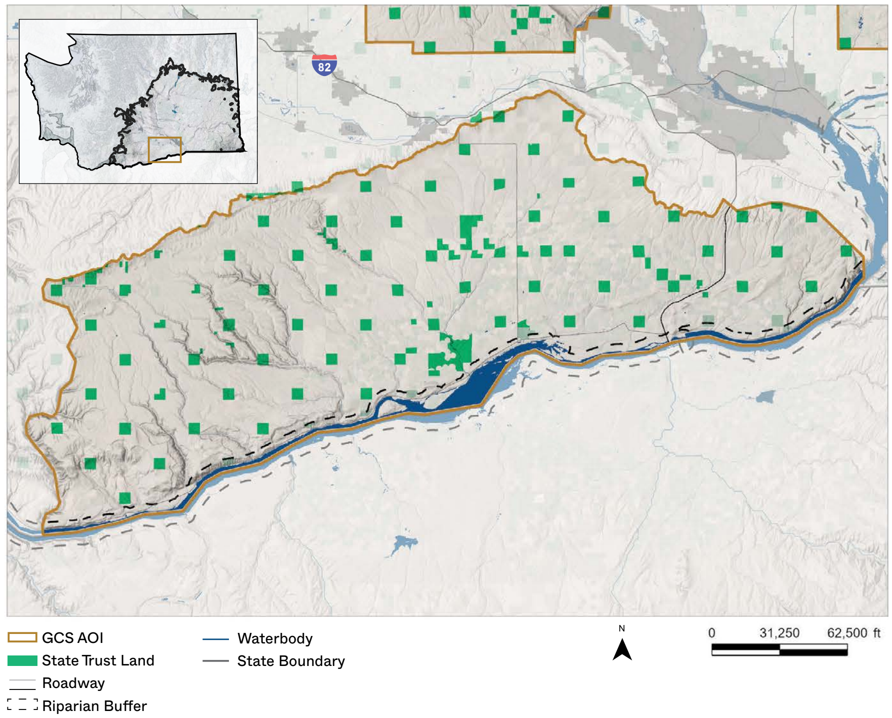

Figure 36. Map highlights the Canoe Ridge/Horse Heaven Hills AOI. State trust lands within 0.5 miles of the Yakama River are displayed in light green, reflecting their higher risk for archaeological resources. Whether a particular trust land has a line of sight to a ridgeline has not been evaluated.

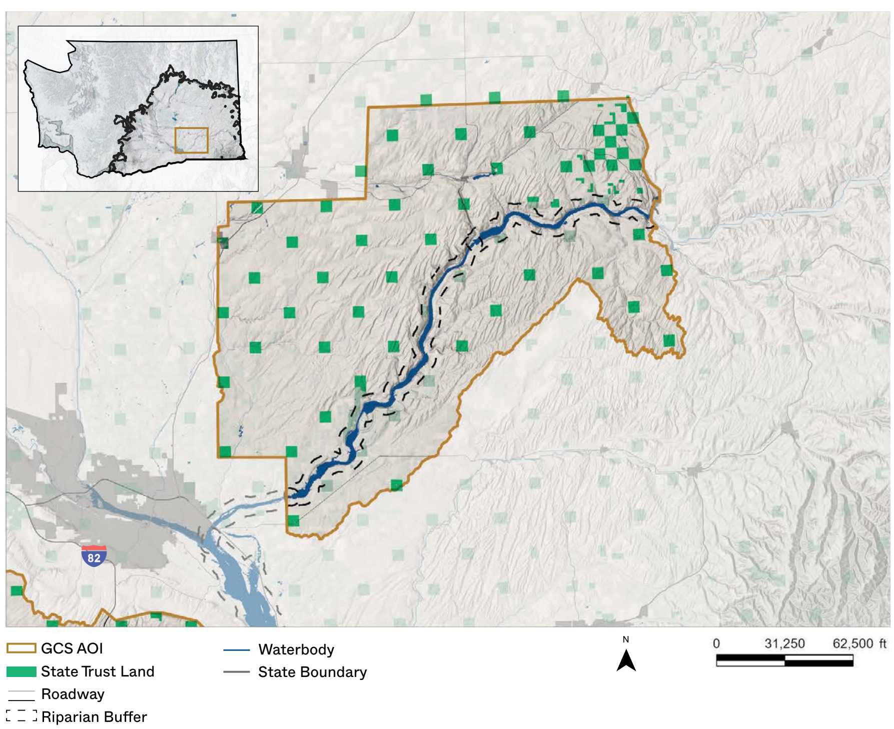

Figure 37. Map highlights the Palouse Slope AOI. State trust lands within 0.5 miles of the Snake River are displayed in light green, reflecting their higher risk for archaeological resources. Whether a particular trust land has a line of sight to a ridgeline has not been evaluated.

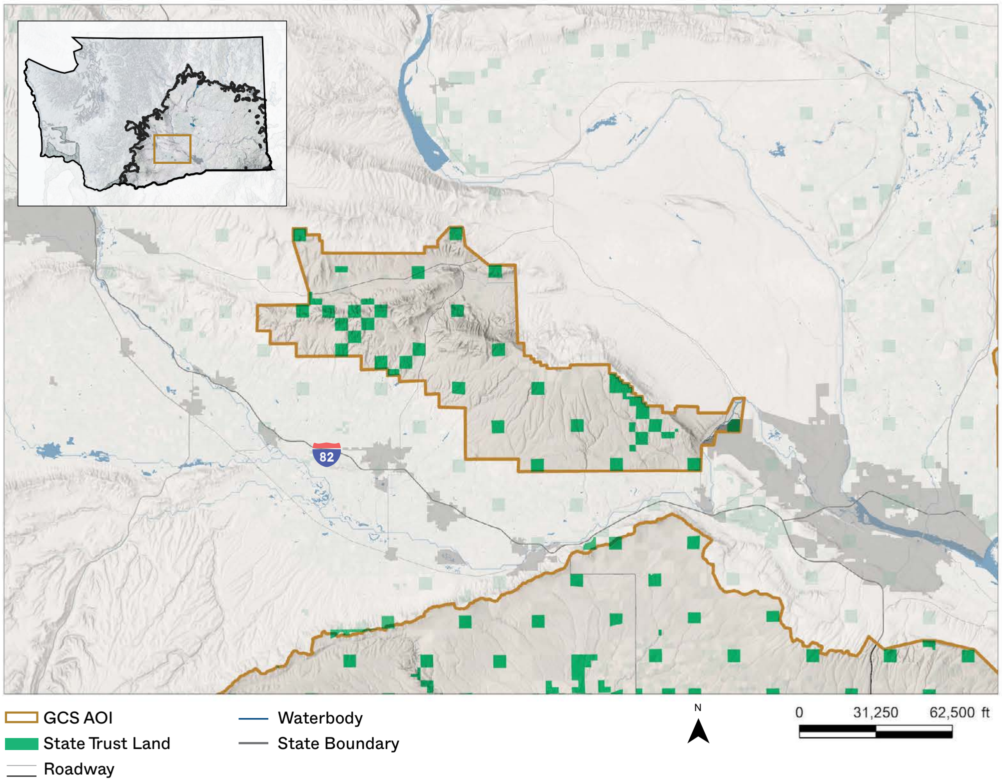

Figure 38. Map highlights the Rattlesnake Hills AOI. Whether a particular trust land has a line of sight to a ridgeline has not been evaluated.

Previously recorded archaeological sites, historic built environment resources, Traditional Cultural Places (TCP), and Properties of Traditional Religious and Cultural Importance (PTRCI) are located within all the AOIs. These resources include, but are not limited to, lithic and can scatters; camps; villages; commercial buildings and residences; roads and railroads; canals; habitation and fishing sites; hunting, medicinal use, and trade areas; ceremonial centers; cemeteries and burial sites; and travel routes. The majority of the archaeological resources, TCPs, and PTRCIs have been identified along waterways, river terraces, and ridgelines, although other geographies also contain these types of resources. Additionally, the Columbia River holds cultural significance to many Indian Tribes. Previously recorded historic built environment resources are primarily located in urban and suburban areas, though transportation corridors often transect rural settings.

Although the AOIs are not within Indian Tribal reservations, the areas hold cultural importance to Indian Tribes. All three AOIs overlap lands ceded by the Confederated Tribes and Bands of the Yakama Nation as part of the Yakama Treaty of 1855 and the Confederated Tribes of the Umatilla Indian Reservation as part of the 1855 Treaty of Walla Walla. Accordingly, both the Confederated Tribes and Bands of the Yakama Nation and the Confederated Tribes of the Umatilla Indian Reservation exercise their Treaty-reserved hunting, fishing, gathering, and pasturing rights within their traditional territories. Additionally, the Confederated Tribes of the Colville Reservation, Confederated Tribes of the Warm Springs Reservation, Nez Perce Tribe, and Spokane Tribe of Indians likely have interests that overlap the AOIs.

Impacts to cultural resources could result from physical disturbance or destruction; changes to significant characteristics; visual, acoustic, and atmospheric changes to a resource's setting; and changes in access to, or use of, a resource. Similarly, impacts to Tribal Treaty rights could result from changes to, or lack of, access and/or use of a Treaty resource or usual and accustomed area. Environmental degradation could also impact Treaty resources such as fish and other aquatic species, terrestrial fauna, plants, or other such resources. **To minimize the risk of impacting Tribal Treaty rights and cultural resources, we recommend that deployment avoid areas near major rivers and their tributaries, as well as ridgelines and areas where Tribal hunting, fishing, and plant gathering occur.**

Should DNR decide to form a P3 to transform the State into a global hub for GCS, then it should begin by inviting government-to-government consultation with the Confederated Tribes and Bands of the Yakama Nation, Confederated Tribes of the Colville Reservation, Confederated Tribes of the Umatilla Indian Reservation, Confederated Tribes of the Warm Springs Reservation of Oregon, Nez Perce Tribe, and Spokane Tribe of Indians to ascertain their receptivity to siting GCS within any of the AOIs and to consider how to minimize impacts to cultural resources.[343] Their input will be essential for preparing a GCS siting strategy, beginning with the CRBG, that dually prioritizes developing the State's basalt resources to fund the public education system and respecting the sovereign rights of those who have stewarded these lands since time immemorial.

Point Sources of CO_2 Pollution

Two other factors important for consideration in a GCS siting strategy are the need for sequestration to meet Washington's climate commitments and the ability to transport CO_2 from facilities capturing or removing carbon to sequestration sites.

All three AOIs are relatively proximate to each other, ranging in distance between 25 and 50 miles apart. Given their relative proximity to each other, we expect distance will not be a major determining factor when developing a siting strategy. CO_2 could be feasibly transported from any emitting facility to each AOI. Still, distance between a CO_2 point source and an AOI varies from 10 to 250 miles, so trucking distance is likely to be a contributing consideration for GCS project developers.

If the natural gas power plants and hard-to-decarbonize industrial facilities identified in Chapter 6: Stocktake of Carbon Dioxide Pollution are retrofitted with carbon capture systems, nine facilities (reporting annual nonbiogenic CO_2 emissions totaling 3.7 million MT) are most proximate to the Canoe Ridge/Horse Heaven Hills AOI, with an average vehicular distance of 140 miles. Four facilities (reporting annual nonbiogenic CO_2 emissions totaling 250,000 MT) are most proximate to the Palouse Slope AOI, with an average vehicular distance of 70 miles. Finally, 18 facilities (reporting annual nonbiogenic CO_2 emissions totaling 12.3 million MT) are most proximate to the Rattlesnake Hills AOI, with an average vehicular distance of 200 miles.

Comparing weighted averages of emissions volumes and trucking distances to the nearest AOI across facilities emitting nonbiogenic CO_2 offers an initial indication as to which might be prioritized as CO_2 sources for GCS. (See Table 8 and Figure 39.)

343. Precontact and historic archaeological sites are protected by the Revised Code of Washington. RCW 27.44 (Indian Graves and Records) and RCW 27.53 (Archaeological Sites and Resources) require that a person obtain a permit from the DAHP before excavating, removing, or altering Native American human remains or archaeological resources in Washington.

Table 8. Ranking of Nonbiogenic CO_2 Sources for GCS Prioritization

Rank	ID	Facility	Sector	Trucking Distance (miles)	Nearest AOI	CO_2 Emissions (MT)
1	E-11	Puget Sound Energy Inc - Goldendale Generating Station	Grid Electrical Natural Gas Power	29	Horse Heaven	825,333
2	E-04	Clark Public Utilities - River Road Gen Plant	Grid Electrical Natural Gas Power	131	Horse Heaven	1,399,077
3	I-13	HF Sinclair Puget Sound Refinery LLC - Anacortes	Petroleum Refineries	221	Rattlesnake	1,890,710
4	I-06	Packaging Corporation of America - Wallula	Kraft Mills	16	Palouse Slope	83,592
5	I-12	bp Cherry Point Refinery - Blaine	Petroleum Refineries	254	Rattlesnake	2,052,443
6	E-05	Invenergy - Grays Harbor Energy Facility	Grid Electrical Natural Gas Power	206	Rattlesnake	1,396,393
7	E-06	PacifiCorp - Chehalis Generating Facility	Grid Electrical Natural Gas Power	163	Rattlesnake	913,796
8	E-19	Spokane Waste-to-Energy	Waste-to-Energy	85	Palouse Slope	124,047
9	E-12	Puget Sound Energy Inc - Mint Farm Generating Station	Grid Electrical Natural Gas Power	168	Horse Heaven	797,939
10	E-03	Capital Power Corp, Puget Sound Energy Inc - Frederickson Power LP	Grid Electrical Natural Gas Power	158	Rattlesnake	707,981
11	I-14	Marathon Anacortes Refinery - Anacortes	Petroleum Refineries	223	Rattlesnake	1,196,960
12	I-09	Inland Empire Paper Company - Spokane	Newsprint Mills	97	Palouse Slope	16,269
13	E-02	Avista Corp - Boulder Park	Grid Electrical Natural Gas Power	103	Palouse Slope	31,424
14	I-17	Georgia-Pacific Consumer Operations LLC - Camas	Tissue and Towel Mill	115	Horse Heaven	48,436
15	I-01	Ash Grove Cement Company - Seattle	Cement Production	162	Rattlesnake	366,730
16	I-05	Nippon Dynawave - Longview	Kraft Mills	167	Horse Heaven	369,145
17	I-16	U.S. Oil & Refining Co. - Tacoma	Petroleum Refineries	157	Rattlesnake	146,643
18	E-10	Puget Sound Energy Inc - Fredonia	Grid Electrical Natural Gas Power	216	Rattlesnake	640,595

Table 8, Continued

Rank	ID	Facility	Sector	Trucking Distance (miles)	Nearest AOI	CO_2 Emissions (MT)
19	E-09	Puget Sound Energy Inc - Frederickson	Grid Electrical Natural Gas Power	158	Rattlesnake	118,560
20	I-15	Phillips 66 Ferndale Refinery - Ferndale	Petroleum Refineries	250	Rattlesnake	898,414
21	I-08	WestRock LLC - Longview	Kraft Mills	166	Horse Heaven	176,257
22	I-03	LANXESS Corporation - Kalama	Chemicals and Hydrogen	155	Horse Heaven	60,058
22	I-03	LANXESS Corporation - Kalama	Chemicals and Hydrogen	155	Rattlesnake	74,611
24	I-11	Greif, Tacoma Mill - Tacoma	Paperboard Mills	157	Rattlesnake	13,047
25	I-04	Solvay Chemicals, Inc. - Longview	Chemicals and Hydrogen	167	Horse Heaven	50,068
26	I-10	North Pacific Paper Company, LLC - Longview	Newsprint Mills	167	Horse Heaven	36,357
27	E-08	Puget Sound Energy Inc - Ferndale Generating Station	Grid Electrical Natural Gas Power	249	Rattlesnake	714,523
28	E-07	Puget Sound Energy Inc - Encogen	Grid Electrical Natural Gas Power	216	Rattlesnake	426,599
29	I-02	Ascensus Specialties LLC - Elma	Chemicals and Hydrogen	200	Rattlesnake	13,845
30	I-07	Port Townsend Paper Corporation - Port Townsend	Kraft Mills	211	Rattlesnake	57,063
31	E-13	Puget Sound Energy Inc - Sumas Power Plant	Grid Electrical Natural Gas Power	255	Rattlesnake	389,219
32	E-14	Puget Sound Energy Inc - Whitehorn	Grid Electrical Natural Gas Power	254	Rattlesnake	308,273
					Total	**16,344,407**

Facilities are ranked by weighted averages of emissions volume and trucking distance to the nearest AOI. Facilities are displayed by their ID in Figure 39, page 125. CO_2 emissions data is from 2023.[344]

344. Ecology, "GHG Reporting Program."

DACCS and BECCS have potential to offset residual emissions. If existing biomass conversion facilities identified in Chapter 6: Stocktake of Carbon Dioxide Pollution are retrofitted with carbon capture systems to become BECCS facilities, 4.6 million MT of biogenic CO_2 annually could have a need for GCS. (See Table 9.) All 23 identified facilities are located within 250 miles of the three AOIs, with 11 located within 150 miles of the three AOIs. The utilization of mechanical thinnings from wildfire mitigation activity at new and existing BECCS facilities could generate a further 22.1 million MT of biogenic CO_2 available for GCS annually.[345]

If carbon capture systems are installed at these existing biomass conversion facilities, four facilities (reporting annual biogenic CO_2 emissions totaling 2.4 million MT) are most proximate to the Canoe Ridge/Horse Heaven Hills AOI, with an average distance of 110 vehicular miles. Seven facilities (reporting annual biogenic CO_2 emissions totaling 837,000 MT) are most proximate to the Palouse Slope AOI, with an average vehicular distance of 110 miles. Finally, 12 facilities (reporting annual biogenic CO_2 emissions totaling 1.4 million MT) are most proximate to the Rattlesnake Hills AOI, with an average vehicular distance of 200 miles.

Comparing weighted averages of emissions volumes and trucking distances to the nearest AOI across facilities emitting biogenic CO_2 offers an initial indication as to which might be prioritized as CO_2 sources for GCS.

Outreach and engagement should occur to determine which of these facilities are interested in supplying nonbiogenic or biogenic CO_2 for GCS, and how transporting CO_2 from those facilities to select state trust lands within the AOIs might affect Tribal Treaty rights, cultural and environmental resources, and local communities.

345. *See generally* Pett-Ridge et al., "Chapter 6: Biomass Carbon Removal and Storage (BiCRS)," *Roads to Removal* (analyzed by the Carbon Containment Lab).

346. Ecology, "GHG Reporting Program."

Table 9. Ranking of Biogenic CO_2 Sources for GCS Prioritization

Rank	ID	Reporter	Sector	Trucking Distance (miles)	Nearest AOI	CO_2 Emissions (MT)
1	B-03	Nippon Dynawave - Longview	Kraft Mills	167	Horse Heaven	1,197,530
2	B-06	WestRock LLC - Longview	Kraft Mills	166	Horse Heaven	1,129,402
3	B-04	Packaging Corporation of America - Wallula	Kraft Mills	16	Palouse	219,269
4	B-23	280 Earth	DAC	48	Horse Heaven	(500)
5	B-07	SDS Lumber Company - Bingen	Miscellaneous Wood Product Manufacturing	63	Horse Heaven	47,338
6	B-11	Guy Bennett Lumber Company - Clarkston	Sawmills	63	Palouse	14,481
7	B-01	Kettle Falls Generating Station - Kettle Falls	Biomass Electric Power Generation	155	Palouse	442,112
8	B-09	Inland Empire Paper Company - Spokane	Newsprint Mills	97	Palouse	15,753
9	B-21	Hampton Lumber Mills Washington Inc. - Randle	Softwood Veneer and Plywood Manufacturing	109	Rattlesnake	56,677
10	B-05	Port Townsend Paper Corporation - Port Townsend	Kraft Mills	211	Rattlesnake	491,477
11	B-13	Hampton Lumber Mills Washington Inc. - Morton	Sawmills	129	Rattlesnake	29,133
12	B-02	Boise Cascade Wood Products, LLC. Kettle Falls Lumber - Kettle Falls	Cut Stock, Resawing Lumber, and Planing	153	Palouse	56,520
13	B-10	Boise Cascade Wood Products, LLC - Kettle Falls	Reconstituted Wood Product Manufacturing	156	Palouse	56,228
14	B-08	Vaagen Bros. Lumber, Inc. - Colville	Miscellaneous Wood Product Manufacturing	154	Palouse	33,076
15	B-22	Rainier Veneer, Inc. - Spanaway	Softwood Veneer and Plywood Manufacturing	156	Rattlesnake	13,241

Table 9, Continued

Rank	ID	Reporter	Sector	Trucking Distance (miles)	Nearest AOI	CO_2 Emissions (MT)
16	B-17	Sierra Pacific Industries - Burlington - Mount Vernon	Sawmills	216	Rattlesnake	309,509
17	B-18	Sierra Pacific Industries - Centralia	Sawmills	172	Rattlesnake	39,000
18	B-16	Sierra Pacific Industries - Aberdeen	Sawmills	221	Rattlesnake	202,493
19	B-19	Sierra Pacific Industries - Shelton	Sawmills	198	Rattlesnake	58,498
20	B-12	Hampton Lumber Mills Washington Inc. - Darrington	Sawmills	218	Rattlesnake	82,200
21	B-20	Weyerhaeuser Raymond Lumber - Raymond	Sawmills	220	Rattlesnake	32,795
22	B-14	Interfor US, Inc. - Port Angeles	Sawmills	243	Rattlesnake	39,023
23	B-15	Port Angeles Hardwood LLC - Port Angeles	Sawmills	242	Rattlesnake	21,342
					Total	**4,587,597**

Facilities are ranked by weighted averages of emissions volume and trucking distance to the nearest AOI. Facilities are displayed by their ID in Figure 39, page 125. CO_2 emissions data is from 2023.[346]

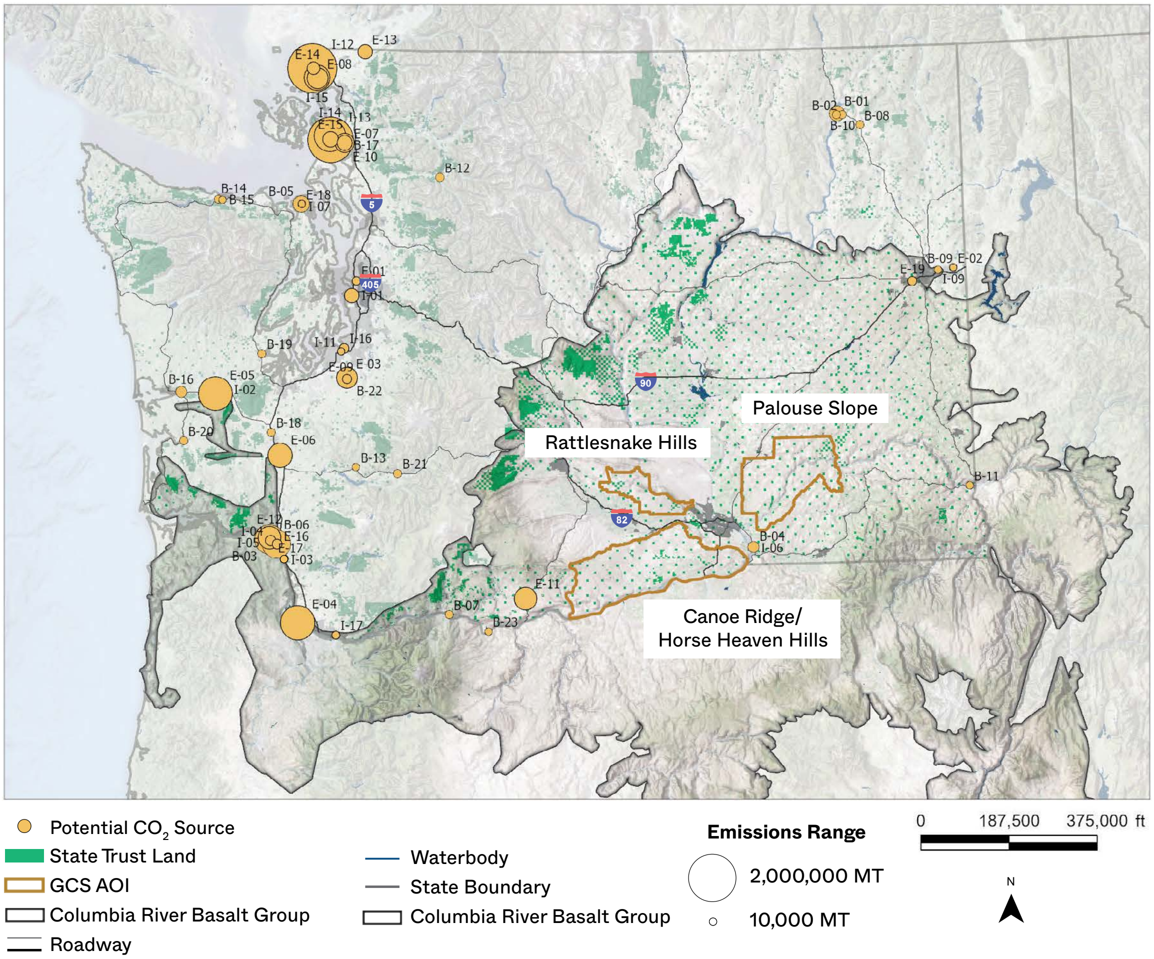

Figure 39. Map displays: emissions volumes of point sources suitable for CCS (i.e., natural gas power plants and certain hard-to-decarbonize industrial facilities) and their locations relative to the CRBG; CO_2 offsetting potential of CDR+S facilities (i.e., biomass conversion facilities that could become BECCS facilities and one existing DAC plant) and their locations relative to the CRBG; major roadways; state trust lands; and three AOIs identified for further GCS exploration. Attribute information corresponding to Facility Source IDs can be referenced in Tables 8 and 9, pages 120 and 123, respectively.

Conclusion

Given all of the hurdles faced by GCS project developers, Washington is unlikely to develop into a global GCS hub without a coordinated effort by key public and private entities. This effort should commence with preparation of a statewide siting strategy, focusing first on these AOIs, so that (1) needed geophysical data is collected in a systematic manner and made publicly available and (2) projects, including CO_2 transportation routes, are not located where Indian Tribes oppose them. We recommend DNR and its P3 partners begin this effort with further exploration and government-to-government consultation. **Data and feedback received should narrow down which state trust lands within the AOIs are suitable for private development.**

III. Public-Private Partnership Planning

Figure 40. Photo of Columbia River basalts, WA. *Shutterstock*.

10. Benefits of Geologic Carbon Sequestration

RECAP FROM PRIOR CHAPTERS

- GCS underpins a thriving CCS and CDR+S ecosystem, providing the most secure and verifiable form of carbon storage and the only durable pathway to achieving GNZ.
    - Washington's ability to meet its clean energy targets in a timely and equitable manner—while maintaining grid reliability and supporting economic growth—depends on expanding access to clean firm power, such as from BECCS.
    - Achieving the State's climate goals requires scaling CDR to offset residual GHG emissions and legacy carbon pollution beginning no later than 2050.
- DNR manages approximately three million acres of state trust lands to produce non-tax revenue for trust beneficiaries, including the public education system. 1,420,800 acres of state trust lands are situated in the CRBG. Of these, 339 parcels, representing 127,588 acres, are situated within three AOIs that may be suitable for GCS.
- GCS injection sites occupy minimal surface area and allow other land uses, like agricultural production, to continue.

Benefits of Geologic Carbon Sequestration

The Washington Climate Partnership recommends advancing GCS to achieve the State's climate and clean energy mandates, create high-quality jobs in underserved regions, spur economic growth, and enhance the quality of life of all Washingtonians.[347] As detailed below, in addition to helping Washington reach its climate and grid stability goals, supporting the creation of a local GCS industry sited on state trust lands will have many social and economic benefits for the State and its communities.

Chapter 2: Climate Goals and Energy Needs describes GCS's importance in meeting the State's net-zero commitments and potential role in providing grid stability.

Social Benefits

GCS will provide direct community benefits through the development of a new green industry, as well as co-benefits that enhance Washington's clean energy transition.

Direct Community Benefits

First and foremost, GCS is necessary for climate resiliency. The State has set emissions targets aligned with keeping global warming below 2°C by 2100. Doing so will require carbon capture from hard-to-decarbonize industrial sources like EITEs, which provide key materials needed for the green energy transition, as well as CDR to draw down legacy carbon pollution from the atmosphere. Among the various options for storing these captured or removed emissions, GCS provides the only safe, long-term means to lock away CO_2 from the atmosphere and achieve GNZ. The State will find it impossible to reach its net-zero goals on schedule without GCS.

Secondly, eliminating the hurdles to GCS would enable a new carbon management industry to grow in Washington—one that would include high-quality green jobs in environmental characterization and monitoring, in addition to those needed to design, construct, and operate CO_2 transportation and injection infrastructure. From engineers, scientists, and geologists to drillers, operators, and community engagement specialists, a diverse set of skills will be needed to support this burgeoning green industry. With the right incentives, GCS startups could base their operations in Washington, bringing job opportunities comparable to those in other U.S. states such as Louisiana and Texas and in other countries. For example, Carbfix currently employs over 60 full-time staff in Iceland and engages hundreds more workers through contracted roles.[348] Pairing such GCS projects

347. Washington Climate Partnership, *Draft CCAP*, 11, 198–20.

348. "Carbfix Receives the Icelandic Innovation Award 2024," The Icelandic Centre for Research, October 29, 2024, https://en.rannis.is/news/carbfix-receives-the-icelandic-innovation-award-2024.

with DAC facilities could further expand the State's GCS-related workforce.[349]

Thirdly, creation of a GCS industry is expected to produce partnerships with local universities, such as Washington State University. Long-term traineeship and internship programs for GCS careers could be established.[350]

Lastly, GCS characterization and monitoring efforts will generate valuable geophysical data, including about groundwater quality, volumes, flow patterns, and aquifer depths. This enhanced understanding of subsurface conditions can support improved water management and planning across the region.

Co-Benefits of GCS to the Ongoing Clean Energy Transition

Washington has a rare opportunity, and responsibility, to foster innovation and investments that create "climate-ready communities," such as by increasing deployment of clean energy technologies—defined to include net-zero-emissions-aligned technologies like renewable energy, energy efficiency, and CCS.[351] GCS can enable and support these clean energy technologies, thereby enhancing the benefits of the State's clean energy transition.[352]

Firstly, Washington must secure clean, firm, affordable, and rapidly deployable power to maintain energy security and prosperity for its residents. Geothermal, nuclear, solar, and wind energy each presently fall short on at least one of these fronts. Retrofitting select natural gas power plants and bioenergy facilities with CCS technologies between now and retirement could help the State to timely secure this clean firm power while renewables with batteries expand to the scale needed. GCS offers a permanent storage solution for the CO_2 captured from these facilities.

Secondly, GCS coupled with BECCS can benefit the State by unlocking the social and economic value of thinning forests in the Pacific Northwest to reduce wildfire risk. The USFS has a 10-year strategy for thinning forests in the region to reduce wildfire risk, which, if executed, is expected to generate 12.0 million BDMT annually in Washington, a volume

349. The construction and engineering of a 500,000 MT DAC plant creates 1,215 annual average jobs over the roughly 5-year time period it takes to build the facility. After the plant is built, approximately 340 jobs are needed to operate the facility over its lifetime. "Direct Air Capture Workforce Development: Opportunities by Occupation," Rhodium Group, October 12, 2023, https://rhg.com/research/direct-air-capture-workforce-development; *see also* "Carbfix and Climeworks Commission the First Large-Scale Permanent Removal of Carbon Dioxide from the Atmosphere," Carbfix, August 25, 2020, https://carbfix.com/newsmedia/carbfix-and-climeworks-commission-the-first-large-scale-permanent-removal-of-carbon-dioxide-from-the-atmosphere.

350. *See, e.g.*, "Workforce Development," Washington State University Energy Program, accessed November 6, 2025, https://www.energy.wsu.edu/researchevaluation/workforcedevelopment.aspx; "Carbfix Project Wins a European Innovation Award," University of Iceland, June 2, 2020, https://english.hi.is/research/carbfix-project-wins-european-innovation-award; "WDTS Internships," PNNL, accessed November 10, 2025, https://www.pnnl.gov/wdts-internships.

351. Ilene Munk, *Climate Ready Communities Implementation status of 2SHB 1176* (Workforce Training and Education Coordinating Board, February 2025), 5, https://wtb.wa.gov/wp-content/uploads/2025/04/2024-CETWAC-legislative-update-.pdf; Office of Energy Jobs, *United States Energy & Employment Report 2024* (USDOE, October 2024), xxvii, https://www.energy.gov/sites/default/files/2024-10/USEER%202024_COMPLETE_1002.pdf.

352. The State has taken significant steps to lay a strong foundation for developing the clean energy workforce, such as by establishing the Washington Climate Corps Network, the Clean Energy Technology Workforce Advisory Committee under the Washington State Workforce Training and Education Coordinating Board, and a Green Jobs Grant Program. *See, e.g.*, "Washington Climate Corps Network," Serve Washington, accessed November 6, 2025, https://servewashington.wa.gov/programs/washington-climate-corps-network; "Clean Energy Technology Workforce Advisory Committee," Washington Workforce Training & Education Coordinating Board, accessed November 6, 2025, https://wtb.wa.gov/cleanenergy; "Green Jobs Grant Program 2025," Commerce, January 23, 2025, https://www.commerce.wa.gov/funding/green-jobs-grant-program-2025.

capable of generating 22.1 million MT CO_2 for GCS if processed at BECCS facilities.[353] Left in the forest, this low-value woody biomass (slash and small-diameter timber) will eventually be re-emitted to the atmosphere via decay, slashpile burning, or combustion in the very wildfires it was intended to suppress. BECCS, enabled by GCS, could utilize this low-value woody debris, building resilience, delivering public health benefits through reduced haze and wildfire smoke, and offering a valuable energy resource. For example, facilities using new, modular gasification technology with carbon capture can convert low-value woody biomass into carbon-negative electricity, while generating carbon-removal credits via GCS.[354] In this way, BECCS can create a new energy market for forest byproducts, strengthening rural economies in Washington.

Thirdly, the Legislature emphasizes that the State should support the long-term prosperity of Washington's businesses, workers, and communities by growing clean energy jobs.[355] The Net-Zero Northwest workforce analysis conducted by CETI concludes that Washington could see a 14% increase in traditional energy-sector employment from 2021 to 2030.[356] Including clean energy jobs enabled by GCS could increase that estimate.

> "The legislature recognizes that climate change is one of the greatest challenges facing the state and the world today, and that we must mobilize Washington's young adults, veterans, and workforce to create the clean energy economy and strengthen our communities and ecosystems in the face of climate impacts."
>
> - HB 1176, 68th Leg., Reg. Sess. (2023)

Other states have already started to capitalize on these opportunities. For example, a BECCS project in Louisiana run by the company AtmosClear aims to capture and store approximately 6.8 million MT CO_2 over 15 years; the project is expected to create 600 construction jobs and 75 permanent operations jobs, while helping to restore jobs in forestry management lost during recent mill closures.[357] In Wyoming, Tallgrass Energy is developing a CCS project to store

353. Forest Service, *Confronting the Wildfire Crisis*, 1; *see generally* Pett-Ridge et al., "Chapter 6: Biomass Carbon Removal and Storage (BiCRS)," *Roads to Removal* (analyzed by the Carbon Containment Lab).

354. *See* United Kingdom Department for Business, Energy & Industrial Strategy, *Power Bioenergy with Carbon Capture and Storage (BECCS) Project Submission–Background and Guidance for Submission* (August 2022), 5, 17, https://assets.publishing.service.gov.uk/media/6304d63e8fa8f5536aea0708/power-beccs-project-submission-guidance.pdf.

355. HB 1176, 68th Leg., Reg. Sess. (2023).

356. CETI, *Workforce Analysis–Washington Key Findings* (April 2024), 1, https://cdn.prod.website-files.com/64512dc345012a0e621f373f/660f2386c1835fa1517ac7e3_CETI_NZNW_Workforce_Key-Findings_Washington_04-2024.pdf.

357. *See* "Microsoft Signs Large Carbon Removal Deal Backing AtmosClear's Louisiana Project," *Reuters*, April 15, 2025, https://www.reuters.com/sustainability/cop/microsoft-signs-large-carbon-removal-deal-backing-atmosclears-louisiana-project-2025-04-15. Microsoft recently announced that it has signed a forward offtake agreement to purchase carbon credits from AtmosClear's BECCS Project in Louisiana, which will begin construction in 2026. *Id*.

approximately 318 million MT CO_2 over 30 years from natural gas power plants supplying a 1.8 GW data center; the project is expected to create 626 construction jobs and 47 permanent operations jobs in the region.[358] Washington can follow suit by developing a GCS industry capable of sequestering between 6.2 and 38.7 million MT CO_2 annually, enabling the creation of hundreds of new clean energy jobs in the broader carbon management industry.

The Legislature also recognizes that the State "must provide support in the transition for workers and communities experiencing declining jobs and revenues associated with high-emissions technologies."[359] When fossil fuel-based power plants are eventually retired, workers at the State's 22 natural-gas power plants will need new employment opportunities.[360] GCS could enable a just green transition by supplying jobs leveraging similar skillsets.

Finally, the mitigation of GHG emissions that GCS enables will have significant public health benefits. The technology for capturing CO_2 from smokestacks can also remove harmful co-pollutants, such as particulate matter, nitrogen oxides, and sulfur dioxide.[361] Cleaner air lowers rates of respiratory and cardiovascular illnesses, reduces hospitalizations, and improves overall well-being, particularly for vulnerable populations in areas historically overburdened by GHG emissions.

Economic Benefits of GCS

In 2023, the Legislature directed DNR to convene the Ecosystem Services Work Group (ESWG) to review existing and emerging markets for ecosystem services, create an asset plan and inventory, and explore potential avenues to monetize ecosystem services on DNR-managed lands.[362] The ESWG considered the potential for eight markets (avoided wildfire emissions, regulatory forest carbon credits, voluntary forest carbon credits, water quantity, water quality, biodiversity, wetland mitigation, and blue carbon credits) for their potential to generate new and diverse revenue streams, but it considered no subsurface resources.[363] This chapter builds upon the ESWG's analysis by determining the potential value of utilizing state trust lands within three AOIs in the CRBG for GCS.

DNR could pursue a strategy of enhancing the value of these lands contemporaneously, or it could prioritize one region at a time. Because this decision should be informed by government-to-government consultation with Indian Tribes and outreach and engagement

358. *See* "Company May Inject Carbon Dioxide Underground in Laramie County," *Wyoming Tribune Eagle*, November 6, 2025, https://www.wyomingnews.com/news/local_news/company-may-inject-carbon-dioxide-underground-in-laramie-county/article_290921c8-c222-11ee-96b4-c757dc578f27.html; *see also* "Cheyenne To Get Massive AI Data Center Powered By Gas And Carbon Capture," *Cowboy State Daily*, July 29, 2025, https://cowboystatedaily.com/2025/07/29/cheyenne-to-get-massive-ai-data-center-powered-by-gas-and-carbon-capture.

359. HB 1176, 68th Leg., Reg. Sess. (2023).

360. Energy Information Administration, "Emissions by Plant and by Region: Final Annual Data for 2023."

361. "Most commercial-scale carbon capture technologies use an amine-based solvent to separate CO_2 from flue gases released by industrial plants and thermal power plants, which require the removal of NOx, SO2, and PM2.5 for optimal performance." Jeffrey Bennett et al., *Carbon Capture Co-Benefits* (Great Plains Institute, 2023), 67, https://carboncaptureready.betterenergy.org/carbon-capture-co-benefits; Hannah Harasaki et al., "Carbon Dioxide Removal Must Be Scaled Responsibly. But What Does That Mean?," World Resources Institute, March 17, 2025, https://www.wri.org/technical-perspectives/responsible-carbon-dioxide-removal.

362. Engrossed Substitute S.B. 5187, chapt. 475, sec. 310(12), 68th Leg., Reg. Sess (2023) (DNR shall develop a state lands ecosystem services asset plan outlining how state lands managed by DNR can be monetized and utilized to reduce overall GHG emissions or to increase carbon sequestration).

363. *See generally* ESWG, *2025 Legislative Final Report* (DNR, August 2025), https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=2025%20Legislative%20Final%20Report_Ecosystem%20Services%20Work%20Group_22439ec3-123f-44ff-9394-dc10e9a5802f.pdf.

with local communities, we assume, for now, that DNR will equally prioritize developing all state trust lands within the three AOIs.[364]

> The Legislature directed DNR to "develop a state lands ecosystem services asset plan[, which outlines] how state lands under the department's jurisdiction can be monetized ... and utilized to ... increase [GHG] sequestration and storage, in the [S]tate."

Investments Needed to Unlock Value

Exploration is required to unlock the full subsurface value of CRBG trust lands. Modern subsurface exploration employs a two-phased approach, combining geophysical remote sensing technologies with selective ground-truthing through test wells. A P3 could distribute responsibility for these characterization costs between GCS project developers and the State, rather than assigning them to a single party, in accordance with these phases. A strong arrangement would ensure the State's upfront costs are minor compared to the potential revenue to the State, trust beneficiaries, and neighboring landowners.

For each of the three AOIs, DNR should first conduct an AEM survey to delineate subsurface and groundwater properties, such as salinity and TDS, to depths of 500 to 1,000 m (≈ 1,640–3,281 ft) at a 2025 cost of approximately \$400 per km^2 (≈ \$1.62/acre). DNR then should focus on the most promising areas and deploy ground-based seismic surveys to depths of 5,000 m (≈ 16,404 ft) at a 2025 cost of approximately \$40,000 per km^2 (≈ \$161.87/acre). At these rates, it would cost approximately \$3.3 million to aerially survey all three AOIs and ground survey the top 5% of state trust lands within them.

Next, site-specific test wells are required. DNR should initially select at least three attractive sites on a transect to study in detail, expanding to additional sites as new data is revealed. At each site, a 500 m (≈ 1,640 ft) test well could characterize CO_2 injection potential. Drilling and studying at this depth would cost approximately \$3.0 million per well, plus costs for logging, testing, conversion preparations, and support services.[365]

GCS project developers would have an incentive to bear the costs of well development in exchange for preference in siting and development at pre-selected state trust lands, especially

364. Cost estimates in this section are based on the Carbon Containment Lab's experience, research, and personal communications with GCS industry members.

365. *See, e.g.*, Holt Services, Inc., "Contract 12922 – Geotechnical Drilling Services: Price Worksheet," Washington State Department of Enterprise Services, 2022, apps.des.wa.gov/contracting/12922p_Holt_10-26-2022.pdf.

if DNR prepares a State Environmental Policy Act (SEPA) nonproject programmatic environmental impact evaluation of GCS development. Such an assessment would cost approximately $2.0 million in total.[366] Alternatively, the State could consider bearing a portion of the costs of well development to increase the likelihood that any successful test well converts to an injection well, raising the State's potential revenues.

Additional Revenue to DNR for Trust Beneficiaries

Revenue from GCS

Revenue from the State's subsurface resources would be additive and could be substantial. Presently, state trust lands within the CRBG are leased for agricultural, grazing, and commercial use. While executed lease rates are not publicly disclosed, typical Washington agricultural land lease rates in 2024 averaged $442 per acre for irrigated cropland, $72.50 per acre for non-irrigated cropland, and $10 per acre for pastureland.[367] Considering the small surface footprint of GCS (≈ 2–5 acres per injection well), DNR could continue leasing the surface estate of state trust lands for these other uses while also leasing a small portion and selling its underlying pore space rights for GCS.

GCS projects can bring in four distinct revenue components for the State:

1. surface lease rates reflecting local markets;[368]

2. pore space purchase prices of $992–$1,191 per acre of pore space unit (averaging approximately $1,092 per acre) or an annual rental fee;[369]

3. injection fees of $2.55–$7.50 per MT CO_2 stored (averaging approximately $5.00 per MT)[370] or a royalty percentage of a GCS project developers' gross proceeds;[371] and

4. other payments as negotiated, such as signing bonuses, advance minimum royalties, or milestone-based bonuses.[372]

366. *See, e.g.*, Ecology, Governor Inslee's 2023–-25 Budget Proposal – Operating, 10, https://ecology.wa.gov/getattachment/42862257-e3cf-4d43-b0cc-e664d2576d53/23-25GovOperating-CapitalSummaryJan2023.pdf.

367. United States Department of Agriculture, National Agricultural Statistics Service, "Cash Rents by County—Washington," 2024, nass.usda.gov/Statistics_by_State/Washington/Publications/Current_News_Release/2024/CSH_CNTY.pdf. Washington 2024 cash rental rates: irrigated cropland, $442/acre; non-irrigated cropland, $72.50/acre; pastureland, $10/acre.

368. Keith Hall, "Carbon Capture and Storage: Models for Compensating Holdout Landowners," *San Diego Journal of Climate & Energy Law*, 14 (2023): 39. https://digitalcommons.law.lsu.edu/faculty_scholarship/475; Keith Hall, "Legal and Regulatory Considerations for Carbon Sequestration Fee Structures," lecture presented at Louisiana State University Law School, Baton Rouge, LA, 2025, 14, https://www.lsu.edu/energy-innovastion/news/files/keith_hall_ccus_iei_may.pdf.

369. Hall, "Carbon Sequestration Fee Structures," 31; R. Lee Gresham et al., "Implications of Compensating Property Owners for Geologic Sequestration of CO_2," *Environmental Science & Technology*, 44, no. 8 (2010), https://pubs.acs.org/doi/10.1021/es902948u. Because mineralization permanently precludes alternative uses of the pore space, we focus on purchasing rather than leasing. Leasing is possible if a perpetual subsurface storage easement is established. We estimate the cost to purchase pore space as the net present value over a 100-year time horizon at a 5% discount rate, beyond which additional costs become insignificant due to discounting. The purchase prices listed correspond to lease rates ranging $50–$60 per acre of pore space unit (averaging approximately $55 per acre).

370. Hall, "Carbon Sequestration Fee Structures," 29, 32.

371. State law has treated other subsurface resources with a 2–20% royalty. *See, e.g.*, WAC 332-22-210 (geothermal); WAC 332-16-035 (mineral prospecting).

372. Other states have collected upfront bonus payments of $34–$425 per acre of pore space unit or tied payments to milestones like the begin-

Exact terms would reflect site-specific geological characteristics, CO_2 volumes and flow rates, and market dynamics. The State can best catalyze development of its world-class storage resource, while increasing revenue available for trust beneficiaries, by offering GCS project developers a scaled payment structure, whereby rental and royalty payments increase incrementally as project operations and profitability grow.[373]

Assuming an individual site occupies five surface acres with 50,000 acres of pore space rights and an injection rate of 500,000 MT CO_2 per year over 20 years,[374] a review of analogous agreements in other states suggests DNR might reasonably expect additional revenues of:

- **Surface lease rates:** $2 per acre per year during exploration, $10 during injection operations, and $2 during monitoring;[375]
- **Pore space purchase prices:** $1,092 per acre; and
- **Injection fees:** $50 per acre of pore space unit per year (at $5.00 per MT CO_2).

This estimation does not include any bonus payments or advance minimum royalties, because minimizing upfront development costs could increase the State's attractiveness for GCS.

Chapter 6: Stocktake of Carbon Dioxide Pollution identifies 14 facilities that in 2023 emitted such volumes of CO_2 that they could benefit from a GCS offtaker capable of receiving 500,000 MT CO_2 per year. These facilities were ranked by emissions and distance from an AOI in **Chapter 9: Siting Prioritization**.

- **Nonbiogenic CO_2 emitters:** 12 facilities—eight of which were ranked among the top 10—emitted volumes of nonbiogenic CO_2 large enough to supply 500,000 MT of CO_2 per year to an injection site. (See Table 8 in Chapter 9.)

ning of injection. See Hall, "Carbon Sequestration Fee Structures," 29–30.

373. *See, e.g.*, WAC 332-22-210.

374. 50,000 acres represents a medium-sized storage unit. *See, e.g.*, Madeleine Lewis, "Issue Brief: Pore Space Utilization for Geologic Sequestration of Carbon Dioxide," University of Wyoming, 2024, carboncaptureready.betterenergy.org/wp-content/uploads/2024/07/SER-Unitiza-tion-Analysis_FINAL.pdf (The Sweetwater Carbon Storage Hub and the Eastern Wyoming Sequestration Hub in Wyoming extend over 50,000 acres of leased surface lands and 200,000 acres, respectively.) It is also possible to vertically stack units when suitable injection zones exist at multiple depths, potentially doubling revenue (e.g., injecting carbonated water at one depth while also injecting supercritical CO_2 at another depth). 500,000 MT CO_2 per year represents a medium-scale injection rate. See, e.g., Toby Lockwood, "Carbon Capture and Storage: What Can We Learn from the Project Track Record?", Clean Air Task Force, effective July 31, 2024, catf.us/resource/carbon-capture-storage-what-can-learn-from-project-track-record; National Petroleum Council, "Chapter Seven—CO_2 Geologic Storage," *Meeting the Dual Challenge* (USDOE, 2021), energy.gov/sites/default/files/2022-10/CCUS-Chap_7-030521.pdf.

375. Washington prospecting leases have annual rentals of $2–$3 per acre, which is significantly more attractive than some other states' GCS exploration rates (e.g., Colorado $12). Rentals during operations are higher ($5–$20 for Washington mining contracts, not including royalty percentages; as of writing, Colorado has not determined rates during GCS operations). *See, e.g.*, WAC 332-16-035; *see also* Rachel Gabel, "First carbon storage project on Colorado state-owned land begins geologic sampling," *The Fence Post*, April 28, 2023, thefencepost.com/news/first-carbon-storage-project-in-colo-begins-geologic-sampling-in-washington-county; U.S. Department of Agriculture, "Cash Rents by County—Washington."

- **Biogenic CO_2 emitters:** the two top-ranked facilities—the Nippon Dynawave and Westrock LLC kraft mills in Longview—emitted volumes of biogenic CO_2 large enough to supply 500,000 MT of CO_2 per year to an injection site. (See Table 9 in Chapter 9.)

Under current UIC Class VI regulations, projects may last as long as 75 years.[376] Competitive lease terms could offer five years for exploration with an option to extend by 70 years (20 years for injection operations and 50 years for decommissioning and monitoring).[377] Due to rapid mineralization rates and the permanence of sequestration in basalt, halved monitoring durations of 25 years may be possible (total project length 50 years).[378] Reduced lease lengths would have minimal impact on revenue to DNR, amounting to a 0.2% increase under this report's methodology.

Revenue from Water Resources

In addition to GCS revenue, DNR might be able to commercialize any water resources discovered during GCS exploration. Given urgent water scarcity in many basins of eastern Washington, the discovery and beneficial use by a GCS project developer of unclaimed potable or near-potable water resources could represent a significant commercial asset for DNR, provided that lease terms establish perfected water rights as appurtenant to the land, ensuring ownership of a perfected water right would revert to DNR upon site closure. Characterization of the deep aquifers beneath state trust lands in the CRBG is currently poor, but GCS exploration has the co-benefit of evaluating nearby aquifers and could potentially reveal previously unidentified deep water resources.

The value of discovering a water source depends on its purity, proximity to demand, and use, but water rights can generally increase Washington property values by five to ten times.[379] Discovery and perfection of a water right during a GCS lease term, such as if the carbonated water injection technique is utilized, could enable DNR to negotiate substantially higher lease rates for future lessees. Reduced CO_2 monitoring periods could potentially capitalize on this value sooner, by transferring the surface lease earlier. As a base case, though such discovery is highly speculative, DNR might estimate a five-fold increase on lease rates of non-irrigated parcels made convertible for an irrigated use. (See Figure 41.)

376. 40 C.F.R. § 146.93(b)–(c) (The USEPA may approve a post-injection site care and site closure plan with a shorter monitoring period).

377. Such a lease structure should be permissible in Washington given that RCW 79.13.060 permits lease terms up to 99 years.

378. 40 C.F.R. § 146.93(b)–(c).

379. R. Troy Peters, "Washington Water Rights for Agricultural Producers," Washington State University Prosser Irrigated Agriculture Research and Extension Center, 2009, irrigation.wsu.edu/Content/Fact-Sheets/FSWR001-WA-Water-Rights-v3.pdf.

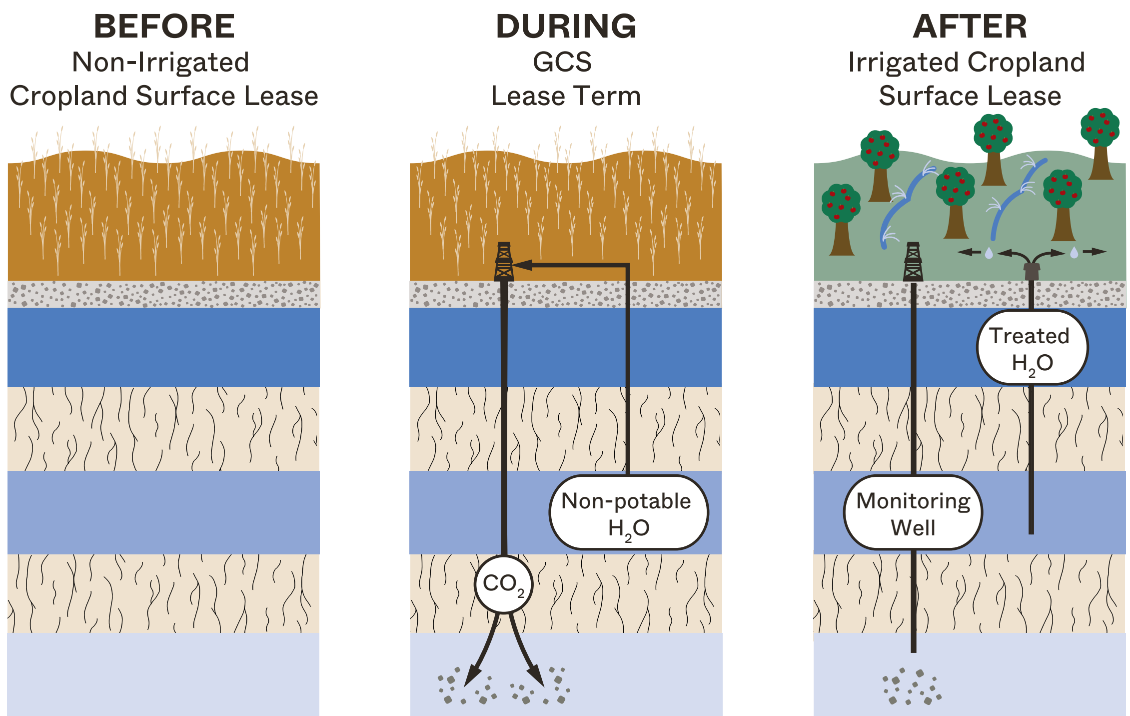

Figure 41. Representation shows how GCS, including perfection of a new water right when the carbonated water injection technique is used, can unlock value in both the subsurface estate (during and after GCS operations) and the surface estate (afterwards), particularly if the water right is appurtenant to the land and reverts to DNR.

Conclusion

Taking these factors together, it is possible to illustrate potential revenue to DNR for trust beneficiaries from commercializing even a small number of sites for GCS. (See Table 10.) **While highly preliminary and subject to verification, discovery and commercialization of just five to ten GCS sites across the three AOIs, including two new water rights, could yield approximately $3.8 to $6.5 million in incremental revenue over a 75-year lease term.** Identifying these resources would require a surveying program estimated to cost $3.3 million, plus $3.0 million or more per test well. By financing much of this upfront investment through a P3, DNR could ensure incremental revenue to trust beneficiaries.

Table 10. Estimated Revenue to DNR for Trust Beneficiaries From GCS and Water Resource Commercialization on State Trust Lands

	Unit Prices	GCS Only ($)	GCS + Water ($)
Pore space purchase/ parcel (one-time)	$1,092/acre	382,072	382,072
GCS surface lease revenue/parcel (75-year total)	5-yr Exploration: $2/acre/yr 20-yr Injection: $10/acre/yr 50-yr Monitoring: $2/acre/yr	585	585
Lost lease revenue from alternative land use/parcel (75-year total)	($73/acre/yr)	(7,063)	(7,063)
Injection fees/parcel (20-year total)	$50/acre/yr of pore space unit at $5/MT CO_2	170,878	170,878
Water incremental surface lease revenue/parcel (50-year total)	$290/acre/yr		539,372
Total: Incremental revenue/ parcel (75-year total)		546,473	1,085,845
Total: Incremental revenue for 5–10 GCS parcels, including 2 with new water right (75-year total)		**2,732,363–5,464,726**	**3,811,107–6,543,470**

Table estimates revenue to DNR for trust beneficiaries from GCS using the carbonated water injection technique and water resource commercialization on state trust lands. Calculations assume a project: leases five acres of a 350-acre parcel of trust land; replaces alternative surface use (non-irrigated crop land) worth $72.50/acre/yr; utilizes 50,000 acres of pore space; and injects at a rate of 500,000 MT CO_2/yr over 20 years. Incremental revenue per parcel for GCS + Water assumes that when the 345-acre lease for the alternative land use ends (illustrated here as concurrent with the cessation of GCS operations), water can be treated for irrigated uses and rents will be renegotiated. Future cash flows are discounted at 5% to show net present value, and all figures are rounded to the nearest dollar.[380]

In addition to revenues to the State and trust beneficiaries, promoting GCS development could enhance property values and flow additional benefits to local governments in the form of increased property taxes. Furthermore, GCS revenue structures, especially those using subsurface unitization, ensure that benefits extend beyond DNR to all landowners above the storage unit. **For a 50,000-acre pore space unit where DNR owns the surface rights to an average 350-acre parcel, more than 99% of the revenue would go to abutting property owners.** At the scale described, neighboring landowners collectively could receive more than $390 million in unitization payments, ensuring broad distribution of benefits from the State's subsurface resources.

380. U.S. Department of Agriculture, "Cash Rents by County—Washington."

KEY TAKEAWAYS:

Social Benefits

- GCS will deliver direct community benefits through the development of a new green industry and co-benefits amplifying the positives of Washington's growing clean energy economy. For example:
    - Developing a GCS industry will generate high-quality jobs across engineering, geology, environmental science, operations, and community engagement.
    - Investing in GCS and related clean energy technologies utilizing CCS could significantly expand Washington's energy-sector employment. Similar projects in other states show that these projects can generate hundreds of construction and many permanent jobs.
    - GCS-enabled CCS can remove harmful co-pollutants, leading to cleaner air and better health outcomes for Washingtonians.
    - GCS-enabled BECCS supports forest management, reduces wildfire risks, and creates carbon-negative energy solutions.

Economic Benefits

- DNR could net significant incremental revenue by conducting a GCS exploration program supported by a robust P3 structure.
- While the exact value is subject to verification, each GCS resource identified on state trust lands could be worth more than $500,000 in addition to existing DNR lease revenue at the site. A modest scenario of five to ten GCS sites could be worth $2.7 to $5.5 million.
- Discovery and perfection of a new water right on state trust lands during GCS development could potentially be worth a further $500,000 or more per site. A modest scenario of two water sources could unlock an incremental $1.1 million.
- GCS economic benefits could extend far beyond DNR, with local governments potentially benefiting from increased property taxes. Neighboring landowners collectively could receive hundreds of millions of dollars of unitization payments.

11. Governance Structure

RECAP FROM PRIOR CHAPTERS

- The Legislature has decreed at RCW 70A.45.100 that "it is the policy of the [S]tate to promote the removal of excess carbon from the atmosphere through ... incentive-based sequestration activities ... [and] in amounts necessary to achieve" net-zero emissions by mid-century.

- The Washington Climate Partnership promotes advancing GCS to achieve the State's climate and clean energy mandates, create high-quality jobs, spur economic growth, and enhance the quality of life of all Washingtonians.

- Unfortunately, siting, regulatory, technical, and financial hurdles unique to first movers deploying in basalt are discouraging progress in the State.

- The benefits for the State of enabling GCS would be many: progress towards meeting climate commitments and building resilience, job growth in eastern Washington, and new significant revenues for trust beneficiaries.

- Federally-recognized Indian Tribes with reservations, ceded territories, and/or other Tribal interests overlying potential sequestration sites situated within the CRBG in Washington most likely include the Coeur d'Alene Tribe, the Confederated Tribes and Bands of the Yakama Nation, the Confederated Tribes of the Colville Reservation, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation, the Cowlitz Indian Tribe, the Kalispel Tribe of Indians, the Nez Perce Tribe, and the Spokane Tribe of Indians. Additionally, the Wanapum Band of Native Americans have traditional lands and interests in the CRBG in Washington.

Governance Structure

State leadership and robust partnerships with public and private entities are needed to eliminate the hurdles preventing GCS deployment and create the enabling conditions for it to flourish.[381] A P3 offers the best opportunity to transform Washington into a global GCS hub. This partnership model leverages the finest attributes of public agency trust, oversight, and policymaking with private sector efficiency and resources. It also facilitates collaboration to distribute risks and costs, so they are not borne disproportionately by one party alone.[382]

The P3's primary objective would be achieving GCS on state trust lands by 2033. Its sub-objectives would be enacting several policies necessary to facilitate GCS and identifying and preparing state trust lands appropriate for GCS for private development. After that, sufficient tailwinds should be established such that Washington would become a leading state for GCS deployment.

A number of interim measures described in Chapter 10: Recommended Next Steps are needed to accomplish these objectives. This chapter first sets forth the governance structure of a P3 vital to achieving them.

Structure

DNR should be the lead state agency. It would oversee identification of state trust lands appropriate for GCS and then contract, after a competitive bidding process, with project developers for lease payments and purchase of pore space rights.

The lead private entity, which we refer to as the Executive Secretariat, would support DNR in achieving the objectives described above. The Executive Secretariat could be formed as a non-profit entity, or consortium of nonprofits, able to obtain private and public funding. It would organize and lead the various P3 partners to eliminate the hurdles that make Washington less attractive than it could be to GCS project developers. The Executive Secretariat could contract with other supporting organizations as needed. DNR and the Executive Secretariat should enter into a memorandum of understanding that sets forth their relative responsibilities according to a mutually acceptable schedule.[383]

Other parties essential for kick-starting Washington's GCS economy include Commerce as the lead agency encouraging and funding economic development and breakthrough climate solutions; Ecology as the state agency with regulatory authority over the UIC program and oversight over the cap-and-invest protocols; the Indian Tribes with reservations, ceded territories, and/or other Tribal interests overlying potential sequestration sites; the Legislature; and GCS

381. *See, e.g.*, EA Engineering, Science, and Technology, Science, and Technology, *CDR Evaluation Study*, 125 (Achieving the scale of CDR+S required to support Washington's commitment to net-zero emissions by 2050 necessitates that Washington "address economic barriers" limiting deployment.); Office of Ground Water and Drinking Water, *UICPG #83*, 4 ("Because of the complexities involved in successfully and safely achieving the goals of a [GCS] pilot project, [s]tates ... may want to pool their resources and form multidisciplinary teams[.]").

382. *See, e.g.*, World Bank Group, "Rooftop Solar Public-Private Partnerships: Lessons from Gujarat Solar," *Partnerships IQ* (2015), 5–6, https://ppp.worldbank.org/library/partnerships-iq-rooftop-solar-ppps-lessons-gujarat-solar.

383. RCW 79.10.130(g) (DNR has authority "to make such leases, contracts, agreements, or other arrangements as are necessary to" manage state trust lands.); RCW 79.02.010(12) (defining "public lands" as including state trust lands); *see also* RCW 43.30.010 (The Legislature established DNR "to provide for more effective and efficient management of the forest and land resources in the [S]tate.").

project developers. Others important to the broader ecosystem that have a role to play include E-NGPP utilities and hard-to-decarbonize industrial facilities considering CCS to reduce their GHG emissions, biomass conversion facilities interested in becoming BECCS facilities, DAC companies, transportation companies (e.g., CO_2 trucking companies and pipeline developers), and landowners adjacent to state trust lands prioritized for GCS who, like DNR, would receive compensation from the project developer for the use of their subsurface estate.

Lastly, an advisory board is key for ensuring that input from rightsholders and stakeholders is incorporated into the design and implementation of this initiative, especially with respect to GCS siting. (See Figure 42.)

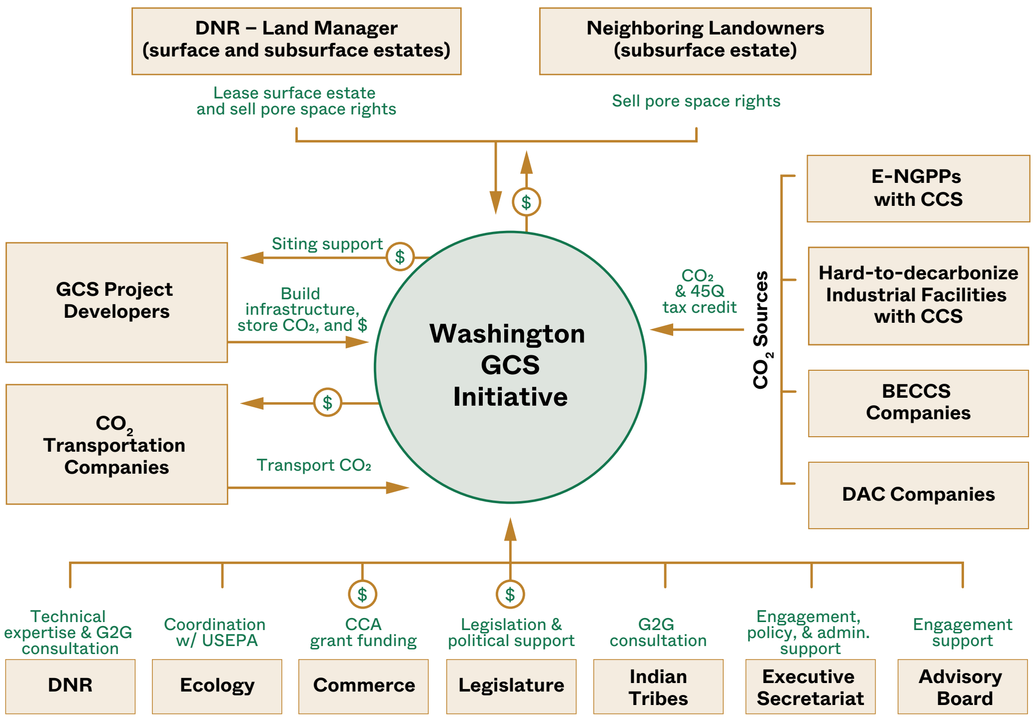

Figure 42. Depiction of the key parties whose participation is fundamental to successfully developing a GCS ecosystem in Washington.

Allocation of Roles and Responsibilities

A well-structured and effective P3 divides roles and responsibilities among the necessary parties by carefully allocating risks and responsibilities to those best equipped to absorb them and to maximize value for the P3 parties. Some of the major risks to Washington's timely becoming a GCS hub, and proposed mitigations to address those risks, are set forth in Table 11. These risks and mitigations inform the governance design of the P3.

Chapter 4: Project Development Hurdles sets forth the challenges that discourage GCS project developers from deploying in Washington. **Chapter 12: Recommended Next Steps** assigns the proposed mitigations below to the P3 partner best able to accomplish them soon.

Table 11. Risks to Washington's Becoming a GCS Hub and Proposed Mitigations

Siting	Paucity of subsurface hydrogeologic data necessary for identifying appropriate GCS sites	Affects GCS project developers utilizing either injection technique by increasing uncertainty in project siting and raising upfront project costs	**Geotechnical surveys and analyses** — DNR oversees subsurface characterization (e.g., AEM surveys and stratigraphic test wells) and requires prompt sharing of GCS project developers' findings to inform a state-wide geospatial database of subsurface resources
Siting	Mistrust and confusion or absence of input from local rightsholders and stakeholders	Affects GCS project developers because siting projects in unwilling communities risks deployment delays; affects local communities, which can be burdened by uninformed siting decisions	**Government-to-government consultation and outreach and engagement** — DNR and Executive Secretariat co-lead process of building trust and reducing the duration of the pre-construction process through early consultation and community engagement to develop a statewide siting strategy; P3 utilizes an advisory board that includes Indian Tribes, landowners, and stakeholders
Siting and Ecosystem	Lack of offtaker for CO_2 captured at hard-to-decarbonize industrial facilities	Affects hard-to-decarbonize facilities interested in CCS, which could incur increased costs by capturing CO_2 and then transporting it long distances for sequestration, as well as the State if climate targets are missed	**Outreach and engagement and policy** — Executive Secretariat drafts legislation to ensure proper regulatory oversight of pipeline siting and safety; Executive Secretariat and DNR or EFSEC receives feedback on potential CO_2 transportation corridors when developing a statewide siting strategy
Siting and Ecosystem	Lack of offtaker for CO_2 captured at E-NGPP utilities' natural gas power plants	Affects E-NGPP utilities interested in CCS, which may need to increasingly turn to rolling brown outs to continue servicing in-state energy consumers while complying with CETA, and affects energy consumers, who, in turn, may grow frustrated with CETA and place its durability at risk	**Policy —** Legislature considers encouraging E-NGPP utilities to utilize CCS to avoid brownouts and continue providing a high standard of living while pursuing clean energy goals
Siting and Ecosystem	Lack of offtaker for CO_2 offsetting residual emissions	Affects the State because DACCS and BECCS companies will be discouraged from developing in-state without a sequestration partner	**Outreach and engagement and policy** — Executive Secretariat and Legislature support co-development of DACCS and BECCS

Table 11, Continued

Regulatory Compliance	Uncertainty whether there is a pathway to commercial scale, Class VI injection in basalts	Affects the State because GCS project developers are deterred from investing in-state	**Geotechnical surveys and analyses and federal-state coordination —** DNR oversees subsurface characterization and requires prompt sharing of GCS project developers' findings to inform a state-wide geospatial database of subsurface resources; Ecology ensures a process for clear coordination with the federal government, including by applying for Class VI primacy and drafting guidance documents
Regulatory Compliance	Uncertain and untested state and federal regulatory regime for sequestering CO_2 in basalts	Affects GCS project developers by increasing time to deployment, thereby increasing project costs and potential liabilities, and risks creating mistrust with local rightsholders and stakeholders	**Federal-state coordination and environmental and cultural assessments and protections —** Ecology ensures a process for clear coordination with the federal government, including by applying for Class VI primacy and drafting guidance documents; DNR builds trust and reduces the duration of the pre-construction process by pre-reviewing sites appropriate for GCS; DNR advances certainty across the industry by requiring project developers to timely share their lessons learned
Regulatory Compliance	Overlapping, complex, and complicated state and federal regulatory regimes	Affects GCS project developers by increasing time to deployment, thereby increasing project costs and potential liabilities, and risks creating mistrust with local rightsholders and stakeholders	**Federal-State coordination and environmental and cultural assessments and protections —** Ecology ensures a process for clear coordination with the federal government, including by applying for Class VI primacy; Ecology drafts guidance documents
Regulatory Compliance	Uncertain whether a water right permit to withdraw commercial-scale volumes of groundwater can be obtained	Affects GCS project developers wanting to use the carbonated water injection technique because their pathway to scale is unclear	**Geotechnical surveys and analyses and outreach and engagement —** DNR and Ecology oversee subsurface exploration (e.g., test water wells) and require prompt sharing of GCS project developers' findings to inform a state-wide geospatial database of subsurface resources; Executive Secretariat, with DNR, considers proximity to sources of treated effluent and industrial process or wastewater, if safe for use for carbonated water injection technique, when developing statewide strategy for siting GCS

Table 11, Continued

Regulatory Compliance	Dearth of state laws on pore space ownership and liabilities	Affects GCS project developers because increases uncertainty over both who to negotiate with and the extent of their potential liabilities	**Legal/Administrative and policy** — Executive Secretariat, with DNR, considers mineral and pore space rights when pre-selecting sites for GCS; Executive Secretariat drafts comprehensive legislation on pore space ownership and liability
Technological	Insufficient or inconsistent stream of high purity CO_2 needing sequestration as State decarbonizes	Affects GCS project developers who might build costly and carbon-intensive sequestration infrastructure that ultimately serves few customers and sees intermittent operations	**Outreach and engagement and policy** — Executive Secretariat and Legislature encourage co-development of DACCS and BECCS
Financial	Upfront project costs are too high to justify developing in basalts	Affects the State because GCS project developers will continue deploying in conventional storage reservoirs in other states	**Geotechnical surveys and analyses and environmental and cultural assessments and protections and policy —** DNR oversees performance of some of the necessary tasks of siting (e.g., technical, cultural, and environmental due diligence required to pre-select state trust lands appropriate for GCS); Commerce commits CCA grant funding
Financial	Lack of established long-term lease agreements for surface estate and purchasing agreements for pore space rights	Affects GCS project developers by increasing upfront GCS project costs and risking unpredictable financial terms, creating uncertainty for project developers and financiers	**Legal/Administrative —** Executive Secretariat, with DNR, prepares template agreements for GCS; DNR requires project developers responding to an RFP to utilize template agreements
Financial	Unavailability of carbon credits under the CCA for CDR+S or CCS	Affects GCS project developers, point sources considering CCS, and DAC facilities by making financing harder to secure because the time to the break-even point is delayed; affects the State by reducing its potential cap-and-invest revenue	**Policy —** State mandates that GCS project developers must gather data beyond what is regulatorily required under the UIC program to help Ecology in creating a robust protocol for issuing carbon credits to high-integrity CCS or CDR with GCS projects

Table identifies the major risks threatening Washington's ability to transform into a global GCS hub. These include risks faced by project developers and the GCS ecosystem at large. Proposed mitigations for each risk are offered. Together, these risks and mitigations inform the P3 governance structure proposed herein by identifying necessary parties and the risks they can alleviate or opportunities they can amplify.

DNR is best suited to lead this effort on behalf of the State. It has the personnel and experience necessary to manage this initiative's technical and social risks. DNR's experts in WGS have particular technical knowledge and skills appropriate for advancing GCS. WGS's responsibilities could be similar to those of DNR's Clean Energy program, which identifies state trust lands suitable for clean energy projects by pre-screening them for environmental and cultural resource considerations that could preclude private project development.[384] In this vein, DNR would ensure that proper geophysical remote sensing and on-site testing is done to identify only the safest injection zones. Staff from the Product Sales and Leasing program could then solicit and contract with GCS project developers. Because CO_2 injection wells would be sited on state trust lands, and because of the trust and respect DNR wields, DNR also should act as the lead agency with responsibilities for engaging potentially interested or impacted Indian Tribes in government-to-government consultation, complying with SEPA at the programmatic level, and coordinating compliance under the National Historic Preservation Act (NHPA) with DAHP. Completing this work in advance of bidding sites has the benefit of reducing potential public opposition, and, therefore, time delays and costs that project developers would otherwise face. The value to DNR of this work is threefold: (1) It follows the Legislature's direction to promote sequestration, (2) achieves DNR's mission of managing state land for the needs of present and future generations, and (3) increases funding available for trust beneficiaries.

Ecology is best suited to handle regulatory uncertainty and lengthy permit processing timelines, all while maintaining its independent regulatory authority. Ecology has great potential to influence the speed with which Washington becomes a GCS hub; for example, if Ecology pursues a delegation of authority to oversee operation of UIC Class VI wells, Ecology can reduce permitting timelines and complexity, attracting GCS project developers to the State. Ecology should also consider developing both a guidance document advising on GCS permitting pathways and protocols to issue carbon credits from high-integrity CCS or CDR with GCS projects. The benefits to Ecology of advancing this initiative include (1) following the Legislature's direction to promote sequestration and (2) expanding the agency's regulatory oversight to protect Washington's resources.

Commerce and the **Legislature** are best equipped to tackle financial shortcomings and to ensure continued political support for this initiative. Commerce's role as the primary booster of a GCS economy is crucial. It should offer CCA grant funding to E-NGPP utilities and hard-to-decarbonize industrial facilities needing CCS and to the first several GCS project developers taking on the regulatory, technical, and financial challenges associated with sequestering in basalt.[385] Support from the Legislature is critical, as well, particularly as it pertains to creating the circumstances necessary for meeting the State's climate and clean energy mandates and promoting a unified vision for a global GCS hub, just like the Legislature did for the Pacific Northwest Hydrogen Hub.[386] The Legislature should enact policies necessary to accelerate GCS, such as those regarding pore space ownership and liability. The benefits to Commerce and the

384. "Clean Energy," DNR, accessed October 19, 2025, https://dnr.wa.gov/product-sales-and-leasing/clean-energy.

385. *See* Washington Climate Partnership, *Draft CCAP*, 108.

386. *See* Substitute S.B. 5910, 67th Leg., Reg. Sess (2022) ("[T]he [L]egislature intends by this act to establish policies and a framework for the [S]tate to become a national and global leader in the production and use of these hydrogen fuels.... The [L]egislature further finds that Washington state is strongly positioned to develop a regional clean energy hub[.]").

Legislature from participating in this initiative include (1) increasing the revenue available to the State and (2) continuing to build the State's reputation as a frontrunner tackling the climate crisis.

Each of the **Indian Tribes** with reservations, ceded territories, and/or other Tribal interests overlying or near potential sequestration sites need not absorb any risk associated with developing a GCS economy, unless they want to be co-owners of a project. Either way, their input is critical to the initiative's success. Washington's potential to develop into a global GCS hub depends on DNR's engaging with these Tribes in government-to-government consultation to learn at an early stage whether they support GCS at certain sites, support transporting CO_2 to those sites, and have any preconditions for safe and responsible development. These Indian Tribes could potentially receive revenue by selling pore space or mineral rights or forest thinnings for use at BECCS facilities.

The **Executive Secretariat** should be the lead private entity for this initiative, working closely with DNR and other P3 partners.[387] The Executive Secretariat would generate and socialize a project plan running from inception to contracting for the first GCS wells on state trust lands. The Executive Secretariat should be composed of or receive support from, at a minimum, qualified legal, financial, technical, and community engagement advisers. Its functions should include supporting the initiative by (1) drafting and helping to pass legislation creating the state laws necessary for GCS, (2) drafting solicitation documents and template legal agreements for expedited leasing and purchasing of pore space rights, (3) supporting DNR's identification and prioritization of state trust lands for GCS, (4) engaging with Indian Tribes, state representatives, and community groups to provide education around GCS and to hear where GCS and transportation corridors are not opposed, and (5), importantly, drafting evaluation criteria to support DNR's bid process. The purpose of the Executive Secretariat is not to receive a benefit but to provide the assistance needed to support this initiative.

This initiative cannot succeed without **GCS project developers**. They should have responsibility for, and the associated risks of, all functions normally undertaken by a project developer, but with its public-sector partner, DNR, shouldering some of the weight of these risks. For example, GCS project developers will have an easier time siting and financing their projects if DNR pre-determines which state trust lands are appropriate for GCS and which communities welcome it.

E-NGPP utilities and hard-to-decarbonize industrial facilities considering use of CCS, DAC companies, and biomass conversion facilities interested in becoming BECCS facilities are also important P3 partners. They would engage with Commerce to ensure they have the technical and financial support needed to capture CO_2 that would otherwise be emitted into the atmosphere. They, along with **CO_2 transportation companies and landowners neighboring state trust lands prioritized for GCS**, also would engage with the Executive Secretariat to inform project siting. A representative of each of these groups should be invited to join the Advisory Board. The benefits to companies capturing or removing CO_2 as part of this initiative include (1) reducing their CO_2 emissions and (2) securing an in-state sequestration partner, which (3) reduces CO_2 transportation costs. CO_2 transportation companies and landowners

387. The Pacific Northwest Hydrogen Hub, Maritime Blue, and the Washington Climate Partnership have governance structures that, collectively, inform the composition and functions of the Executive Secretariat and Advisory Board.

selling pore space rights would receive economic benefits should GCS flourish in Washington.

The **Advisory Board** need not absorb any risks, though it is an important part of the P3 because inclusive planning makes climate action more effective, equitable, and prompt.[388] The Advisory Board should be composed of diverse rightsholders and stakeholders, such as representatives of Indian Tribes, industry, environmental organizations, labor, PNNL, carbon credit buyers, and academia committed to responsibly developing Washington into a global GCS hub. Advisory board members would have primary responsibility for (1) sharing their expertise and representing the perspectives of their constituents to inform development of a statewide GCS siting strategy and (2) advising DNR, the Executive Secretariat, and other P3 partners by providing input when the criteria and weighting to evaluate bids from project developers are set. Those who participated in DNR's former Carbon Sequestration Advisory Group could be invited to join the Advisory Board as founding members. The benefit to participating on the Advisory Board is that each of these entities will have a voice, providing feedback that is considered for early incorporation into the initiative's design and implementation, which, in turn, would make the initiative more resilient.

Transforming Washington, which has had only one small CO_2 injection in its history, into a global GCS leader is an ambitious undertaking. But with a P3, near- and long-term progress is achievable.

KEY TAKEAWAYS:

- A P3 offers the best opportunity to transform Washington into a global GCS hub. This partnership model leverages the finest attributes of public agency trust, oversight, and policymaking with private sector efficiency and resources.
- The P3's primary objective would be achieving GCS on state trust lands by 2033.
- Key P3 partners include: DNR; Ecology; Commerce; the Legislature; Indian Tribes with reservations, ceded territories, and/or other Tribal interests overlying or near potential sequestration sites; an Executive Secretariat; GCS project developers; E-NGPP utilities and hard-to-decarbonize industrial facilities considering use of CCS; DAC companies; biomass conversion facilities interested in becoming BECCS facilities; CO_2 transportation companies; landowners neighboring state trust lands prioritized for GCS; and an Advisory Board.

388. Washington Climate Partnership, *Draft CCAP*, 40.

12. Recommended Next Steps

RECAP FROM PRIOR CHAPTERS

- Washington could become a global leader in an industry of the future and meet its climate and clean energy commitments by developing its basalt resources.
    - Three AOIs are promising and should be explored: Canoe Ridge/Horse Heaven Hills, Palouse Slope, and Rattlesnake Hills. 339 parcels of state trust lands, representing 127,588 acres, are situated within these AOIs.
- However, without substantial political, financial, and policy support, the State's potential to serve as a GCS hub will remain unrealized because GCS projects in CRBG presently face significant development hurdles compared to those in conventional storage reservoirs like depleted petroleum reservoirs or deep saline aquifers.
- A P3 offers the best opportunity to eliminate these hurdles on the time-scale needed to combat the climate crisis. Key partners include DNR, Ecology, Commerce, the Legislature, Indian Tribes, point sources considering CCS, CDR companies, GCS project developers, CO_2 transportation companies, and landowners neighboring state trust lands prioritized for GCS, as well as a newly formed Executive Secretariat and Advisory Board.

Recommended Next Steps

We recommend a number of critical next steps to transition GCS and the P3 we recommend above from idea to reality. Measures include government-to-government consultation, federal-state coordination, outreach and engagement, legal/administrative activities, geotechnical advances, environmental and cultural assessments and protections, economic assessments, and policy development (legislative and regulatory). **With DNR's encouragement, the P3 partners will be motivated to accomplish the following action items within three years, setting the conditions for a GCS economy to flourish in Washington.**

Government-to-Government Consultation

- **DNR—**conducts government-to-government consultation with Indian Tribes with reservations, ceded territories, and/or other Tribal interests overlying potential sequestration sites within the CRBG in Washington[389] to determine each Tribe's priorities regarding a statewide strategy for siting GCS. Specifically, DNR should consult each Tribe about its: (1) receptivity to siting GCS at some of the state trust lands within the three AOIs identified,[390] (2) interest in participating on a P3 advisory board, (3) perspective on temporary use of CCS at natural gas power plants, (4) perspective on developing CDR projects near GCS sites, and (5) related Tribal priorities, as well as to (6) ensure environmental justice is prioritized.

Federal-State Coordination

- **Ecology—**seeks UIC Class VI primacy and coordinates with USEPA to clarify basalt-specific permitting requirements under the SDWA and RCRA.

Outreach and Engagement

- **Executive Secretariat—**conducts comprehensive stakeholder engagement with GCS project developers, point source carbon emitters, CDR companies, state and local representatives, environmental organizations, landowners abutting state trust lands within the three AOIs, carbon credit buyers, and community groups, including climate, labor, and agricultural interests to: (1) determine their receptivity to GCS at some of the state trust lands within the three AOIs identified, (2) build public support for environmentally responsible and culturally sensitive GCS, and (3) ensure EJ is prioritized.

- **Executive Secretariat—**collaborates with the working group recommended by the Washington Climate Partnership, which, once established, will identify potential CO_2 transportation corridors.

- **Advisory Board members—**conducts informal community outreach and engagement to inform feedback provided to P3 participants and build public support for GCS.

389. These Indian Tribes most likely include the Coeur d'Alene Tribe, the Confederated Tribes and Bands of the Yakama Nation, the Confederated Tribes of the Colville Reservation, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation, the Cowlitz Indian Tribe, the Kalispel Tribe of Indians, the Nez Perce Tribe, and the Spokane Tribe of Indians. Additionally, the Wanapum Band of Native Americans have traditional lands and interests in the CRBG in Washington.

390. Use of State's other basalt resources, including its marine basalts, should be considered later.

Legal/Administrative

- **DNR and Executive Secretariat**—enter into a memorandum of understanding that clearly delineates roles and responsibilities for enabling GCS.
- **DNR and Executive Secretariat**—create template agreements for:
    - leasing a portion of the surface estate of state trust lands for GCS; and
    - purchase and sale of underlying pore space rights.
- **DNR and Executive Secretariat**—prepare an RFP to invite bids from GCS project developers seeking to operate on pre-selected state trust lands.

Geotechnical Surveys and Analyses

- **DNR**—after initial government-to-government consultation and community outreach and engagement, oversees surveys using geophysical remote sensing to characterize the subsurface noninvasively at state trust lands within the three AOIs pre-selected for further exploration.

  Deep surveys are necessary to understand the full hydrogeology of the basalt flows:

    - Start with airborne electromagnetic surveys to delineate subsurface and groundwater properties, such as salinity and TDS, to depths of 500 to 1000 m (≈ 1,640–3,281 ft), quickly and cost effectively.
    - Follow up with seismic surveys to delineate geologic structures to depths of 5 km (≈ 3 miles), including faults that may control compartmentalization of aquifers.
- **DNR and GCS Project Developers**—DNR, or GCS project developers under DNR oversight, drill a series of stratigraphic test wells at a handful of sites identified by remote sensing as most promising, to calibrate the remote-sensing surveys, ground truth assumptions, and provide cores, well logs, and water samples for further analysis.
- **DNR and Ecology**—using the geophysical remote sensing and test well results, develop a detailed hydrogeologic characterization of aquifer systems on state trust lands within the three AOIs, including deep aquifers, to quantify water availability, assess withdrawal sustainability, and evaluate potential impacts on overlying resources.
- **Executive Secretariat**—assists with all of the above, including by assessing mineral and pore space rights underlying potential sequestration sites.

Environmental and Cultural Assessments and Protections

- **DNR and Ecology**—prepare a SEPA nonproject programmatic environmental impact statement evaluating the impacts of GCS on state trust lands within the three AOIs to which GCS project developers can subsequently tier their site-specific assessments.
- **DNR and DAHP**—develop a programmatic agreement under the NHPA that GCS project developers can subsequently tier to.
- **Ecology**—issues guidance for siting and permitting Class V and VI wells.
- **DNR and Ecology**—develop a strategy for long-term monitoring of wells on state trust lands.
- **Executive Secretariat**—assists with all of the above.

Economic Assessments

- **Executive Secretariat**—collaborates with owners and operators of natural gas power plants and hard-to-decarbonize industrial facilities interested in CCS to refine a capture-economics analysis of different CO_2 sources, to advance decarbonization efforts.
- **Executive Secretariat**—develops a financial analysis of the extent of GCS exploration to be conducted, building on the revenue and cost estimates presented here and incorporating cost share with GCS project developers.

Policy Development

- **Legislature and DNR**—by statute or other administrative action announce the State's intention to offer pre-selected state trust lands for GCS, for the benefit of the public school system.
- **Ecology**—with input from the State's Agriculture and Forestland Carbon Capture and Sequestration Advisory Panel, establishes and adopts a GCS protocol for issuing carbon credits under the CFS and CCA.
- **Legislature, EFSEC, UTC, and Executive Secretariat**—Executive Secretariat, in coordination with EFSEC and UTC, drafts legislation expanding their jurisdictions over CO_2 pipeline siting and safety, respectively, and drafts regulations governing CO_2 pipeline safety for all three phases of CO_2.

- **Legislature, DNR, and Executive Secretariat—**Executive Secretariat, in collaboration with DNR, drafts regulations eliminating barriers to GCS development, particularly related to:
    - pore space ownership;
    - pore space unitization;
    - pore space encroachment; and
    - the transfer of both responsibility for long-term monitoring and post-closure ownership of injected CO_2 and liability to the State.
- **Legislature and Executive Secretariat—**Executive Secretariat drafts for the Legislature's consideration an extended producer responsibility law (i.e. Carbon Takeback Obligation), obligating covered entities (E-NGPP utilities and hard-to-decarbonize industrial facilities) to capture and deliver their CO_2 emissions for permanent GCS.
- **Commerce and Executive Secretariat—**Executive Secretariat, in coordination with Commerce, outlines a competitive CO_2 procurement program to catalyze wide-scale commercialization of CDR+S solutions.
- **Legislature—**considers whether there is a near-term need to protect CETA by slightly modifying it to incentivize E-NGPP utilities to retrofit their existing plants that are far from retirement with carbon capture systems, and, if so, enacts legislation.
- **Commerce—**commits state CCA grant funding to enable GCS, including by funding installation of CCS infrastructure, deployment of CDR+S, outreach and engagement to inform a statewide GCS siting strategy, and DNR-led geophysical remote sensing surveys.

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