Proceedings World Geothermal Congress 2026
Calgary, Canada, June 8 – 11, 2026

Pathways to Utilizing Overlooked Pore Space: CO_2 Plume Geothermal in the Columbia River Basalt Group

Jonathan D. Ogland-Hand[1]*, Matt Villante[2], Benjamin M. Adams[1], Lydia Bailey[1], Stephanie DiRaddo[2], Richard S. Middleton[1]

[1]Carbon Solutions, Saint Paul, MN USA, [2]Pacific Northwest National Laboratory, Richland, WA, USA

*E-mail address for corresponding author: jonathan.ogland-hand@carbonsolutionsllc.com

Keywords: CO_2 Plume Geothermal, CPG, Columbia River Basalt Group, CRBG, CCS, CCUS, LCOE

ABSTRACT

CO_2 capture and storage (CCS) is the process of capturing CO_2 from point sources and permanently storing it underground, and CO_2-plume geothermal (CPG) takes this process a step further by intentionally circulating a portion of the stored CO_2 back to the surface and using it to generate geothermal power. Past CPG work has focused on investigating CPG within sedimentary basin geologies and this study explores the application of CPG technology within the Columbia River Basalt Group (CRBG) in the Pacific Northwest, USA. We conduct a literature review to determine potential distributions of geologic properties within the CRBG and use those ranges to bound the uncertainty in levelized cost of electricity (LCOE) of CPG. We also estimate the quantity of CO_2 available from point sources in the Pacific Northwest to evaluate if insufficient CO_2 volumes constrain CPG potential. We find that there are approximately 40 $MtCO_2$/yr of CO_2 available from point sources, which could enable upwards of ~20 MWe of CPG power capacity. LCOE estimates vary between <$50/MWh and >$200/MWh due to geologic uncertainty and the sensitivity of LCOE within the geologic bounds of the CRBG. We thus conclude with the suggestion of drilling deep exploration wells to reduce the uncertainty in geology and heat flow as a way to further assess the potential of CPG in basaltic provinces.

1 INTRODUCTION

CO_2-Plume Geothermal (CPG) power plants use geologically stored CO_2 as the heat extraction fluid for power generation. In CPG power plant operation, sequestered CO_2 is intentionally produced from the subsurface, expanded through a turbine to make electricity, cooled and condensed, and then re-injected into the subsurface for permanent storage. Our prior work has demonstrated that, compared to water, using CO_2 as the heat extraction fluid results in: a) more geothermal heat extracted (Adams *et al.*, 2015); and b) lower-cost electricity generation (Adams *et al.*, 2021); thus ultimately c) doubling the United States sedimentary basin geothermal resource base (equating to hundreds of gigawatts of new capacity) by enabling electricity generation in geologies that are otherwise too impermeable, too thin, too cold, or not deep enough (Cairncross *et al.*, 2024). In this way, CPG technology "unlocks" sedimentary basin geothermal resources, which are generally regarded as being too cold to support electricity generation when water is used as a heat extraction fluid (Porro *et al.*, 2012).

Here, we explore the potential for CPG power production in another potentially overlooked subsurface resource: low-temperature basalt formations. Basalt formations are globally ubiquitous, covering >5% of the continental land surface and are present on all continents (Snæbjörnsdóttir *et al.*, 2020). Basalt-hosted reservoirs have been studied or utilized for a variety of subsurface applications including high-temperature geothermal energy production, hydrocarbon production, groundwater production, and carbon sequestration (Millett *et al.*, 2024). Lava flow emplacement mechanisms result in contraction during cooling and degassing of volcanic gas, which generate fractures and vesicular porosity – leading to reservoir porosity. These mechanisms – in addition to secondary mechanisms like alteration - result in stacked alternating flow interiors (low permeability) and high-permeability flow tops that can exceed 40% porosity and permeability that >1 Darcy permeability (Millett *et al.*, 2024). Continental flood basalts can host extensive (>10,000 km^2), voluminous (>1,000 km^3) stacked reservoir systems (Bryan *et al.*, 2010; Millett *et al.*, 2024) with elevated heat flow that could enable subsurface energy applications such as CPG.

We specifically focus on the Columbia River Basalt Group (CRBG) in the Pacific Northwest of the United States as a case study due to its suitability for commercial-scale CO_2 storage (Blondes *et al.*, 2019; Cao *et al.*, 2024). For example, the CRBG hosted the Wallula CO_2 injection pilot project, which validated its storage potential (McGrail *et al.*, 2017). But the potential that this CO_2 storage resource has for providing geothermal power via CPG technology has yet to be explored. Unlike sedimentary basins with extensive exploration history for resources like hydrocarbons, deep (i.e., >1 km) subsurface data in the CRBG is sparse, which constraints understanding of deep geothermal potential in the region (Burns *et al.*, 2016).

2 METHODS

Our methodology consists of three tasks, listed below, which collectively explore the potential that the CRBG may have to support CPG from two standpoints: geology and CO_2 availability. Although CPG technology can "unlock" locations that would be otherwise be too expensive when water is used as a heat extraction fluid, it is still possible for geologies to be not conducive to low-cost power generation with CPG (Ogland-Hand *et al.*, 2022; Cairncross *et al.*, 2024). Additionally, CPG power requires megatonnes of CO_2 storage to generate megawatts of electricity (Adams *et al.*, 2021), so it is possible for a lack of CO_2 to constrain the development of CPG power more than geology. In other words, it is important to consider both geology and CO_2 source availability when investigating the potential for CPG in any given location.

1. We performed a literature review to compile geologic data for the CRBG, specifically formation thickness, geothermal gradient, depth, and permeability. More details of this work are provided in Section 2.1.

2. We used prior work to estimate the levelized cost of electricity (LCOE) of CPG across a range of representative geologic conditions. Then, using the data collected from the CRBG, we bounded the subset of estimated LCOEs that may be present within the CRBG geology. More details of this methodology are provided in Section 2.2.

3. We used prior work to identify how much CO_2 may be available for capture from point sources around/within the regional extent of the CRBG. More details of this effort are provided in Section 2.3.

2.1 Literature Review: Geologic Data for the Columbia River Basalt Group

The CRBG in the Pacific Northwest of the United States is a thick series of >350 lava flows erupted between 16.7 and 5.5 million years ago, covering over 200,000 km^2 with an estimated volume of 210,000 km (Reidel *et al.*, 2013) (Figure 1). The CRBG has been divided into seven geologic formations: Steens Basalt, Imnaha Basalt, Picture Gorge Basalt, Prineville Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt (Reidel *et al.*, 2013). Of these, the Grande Ronde Basalt is the most extensive formation, making up ~72% of the CRBG. The number, thickness, and extent of individual lava flows within these formations depends on multiple factors, including proximity to eruptive centers (i.e., vents), emplacement volume, viscosity, cooling processes, and paleoenvironmental factors like erosion and topography (Burns *et al.*, 2011). Previous studies exploring the potential for CRBG reservoirs to host natural gas storage indicate flow thickness ranges from 3 to 100 m, with gross lava thickness in the central part of the CRBG potentially up to 5 km (Burns *et al.*, 2011) (Figure 1). Within individual lava flows, reservoirs are hosted primarily by vesicular flow tops or flow-top breccias, which typically make up ~10-20% of the total flow thickness – but with variability from <1% to >90% of total flow thickness (Reidel *et al.*, 2013). These flow top reservoirs can exhibit porosity upwards of >25% and permeability >1 Darcy (Cao *et al.*, 2024). Massive lava flow interiors formed by slow cooling make up the sealing portion of the reservoir-seal system, with very low permeability and porosity preventing vertical CO_2 migration. The general structure of an individual CRBG lava flow is shown in Figure 2a, along with expected permeability and porosity trends for typical lava flow morphologies in Figure 2b.

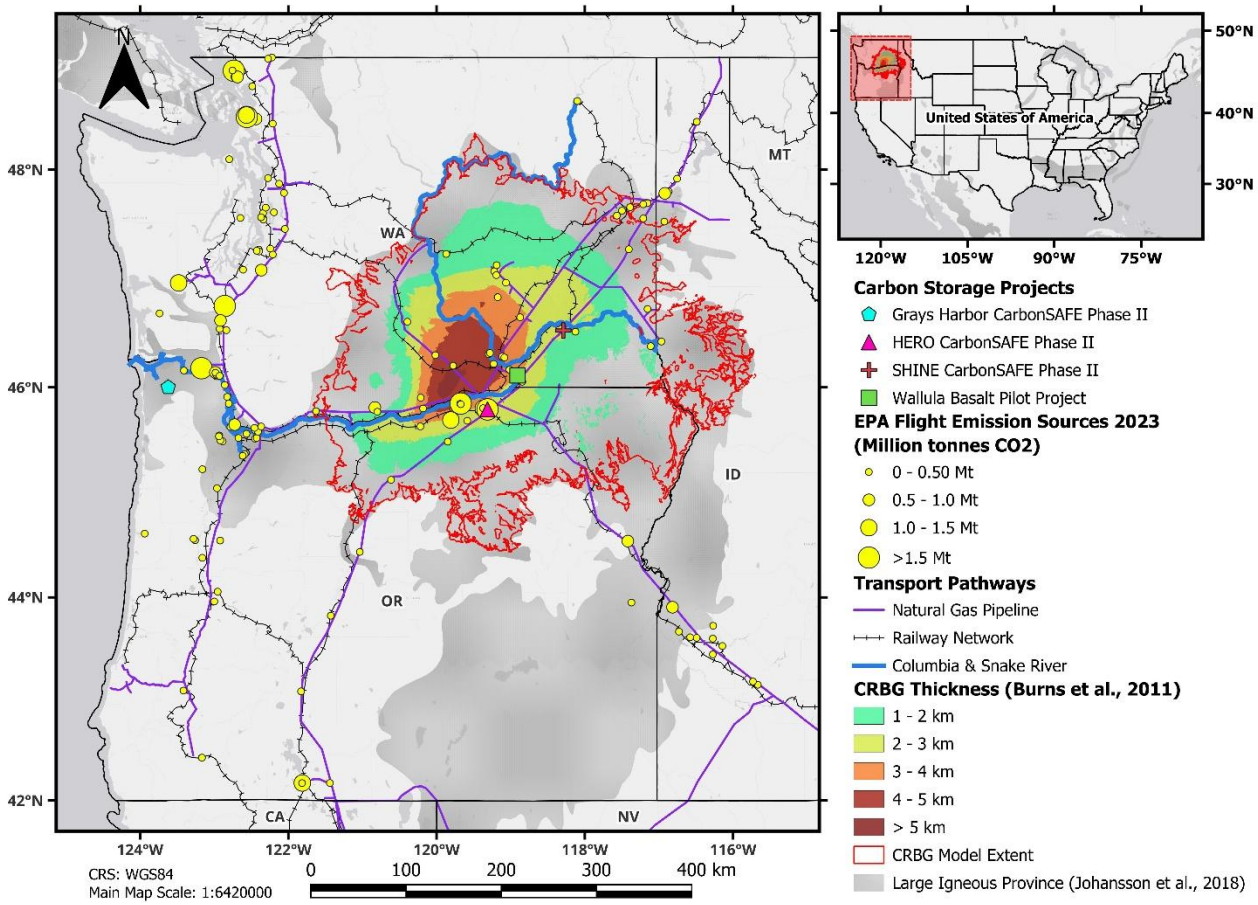


Figure 1. Regional overview showing geologic model extent and thickness of the Columbia River Basalt Group (CRBG) from Burns et al., 2011, extent of other regional large igneous province formations (Johansson, Zahirovic and Müller, 2018), CO_2 emission sources in 2023 (EPA, 2023), potential CO_2 transport pathways (pipeline, rail, and rivers), and previously completed or planning-stage carbon storage projects.

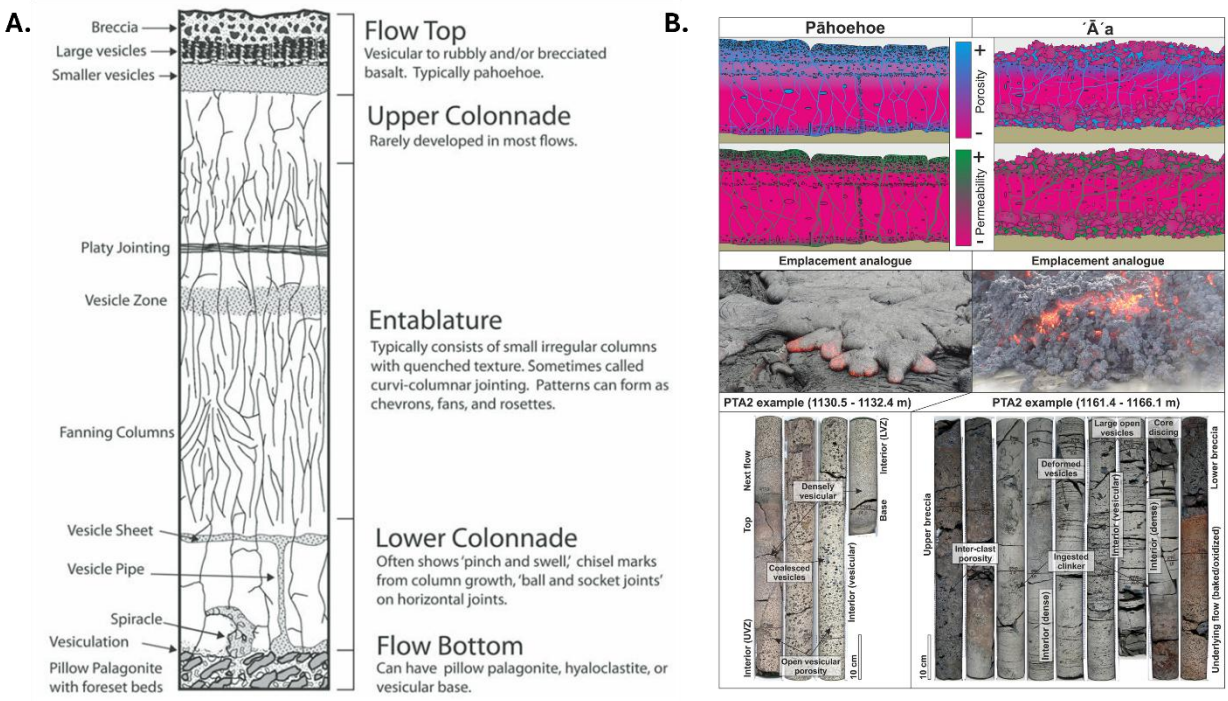


Figure 2. A) Diagram of typical CRBG lava flow features (Reidel *et al.*, 2013), and B) Schematic of relationship between lava flow morphology and flow properties (i.e., porosity and permeability) (Millett *et al.*, 2024).

2.2 Levelized Cost of Electricity Calculations for CPG

We used data from genGEO (Adams *et al.*, 2021; Ogland-Hand *et al.*, 2022) to estimate the LCOE across a wide parameter space of depths and reservoir transmissivities: 1 to 7 km deep and 100 to 10,000,000 mDm. Reservoir transmissivity is the product of reservoir thickness and reservoir permeability. Further, we also used the Ormat financing assumptions from prior work (Ogland-Hand *et al.*, 2022) to estimate the LCOE: capacity factor of 95%; capital recovery factor of 6.2%; and an annual O&M fraction as 5.5% of Capex. We then overlay the range of depths and reservoir transmissivities that may be present within the CRBG based on our literature review findings (Section 2.1) on the cost curves to illustrate potential expected costs for CPG in CRBG formations. As such, this application assumes that pressure losses and heat transfer through basalts behave similarly as within a sedimentary basin.

2.3 CO_2 Source Discovery

We considered all CO_2 point sources within the Pacific Northwest region of Washington, Oregon, and Idaho. Considering publicly available CO_2 emissions tracking data from EPA's Greenhouse Gas Reporting Program (GHGRP) Facility Level Information on GreenHouse gases Tool (FLIGHT) (EPA, 2023), we quantify the potential CO_2 sources available in the region.

3 RESULTS

We present the potential for the CRBG geology to support CPG in Subsection 3.1 and the CO_2 source discovery in Section 3.2.

3.1 LCOE of CPG Power within the CRBG

3.1.1 Range of Geologic Conditions Informed by Literature Review

Compiling previously reported literature data, we determined a range of transmissivity, depth (thickness), flow top thickness, temperature gradient, and other parameters relevant to evaluating CPG in the CRBG. Permeability datasets (Jayne and Pollyea, 2018) based on well test data indicate that adequate transmissivity may exist at depth >1 km in the CRBG, indicating suitable reservoirs may be found at depths where temperatures are high enough for viable CPG (Figure 3). To develop a boundary for expected permeability, we assume flow top thickness between 10 – 30 m and assume sufficient lava exists within the CRBG extent modeled in prior work (Burns *et al.*, 2011). For this analysis, we assumed a permeability range between 50 - 2500 mD and applied the flow top thickness from above to obtain transmissivity values. The upper range of the permeability value assumption is reflective of injectivity test derived permeability values of reservoirs from the Wallula Basalt Pilot Project (McGrail *et al.*, 2014; Cao *et al.*, 2024). The geologic model from Burns et al., 2011 indicates that portions of the CRBG exist at depths between 2 - 5 km (Figure 1), which establishes our assumed upper limit for depth of injection and production. Lastly, we also assume geothermal gradients between 35 – 40 C/km (Burns *et al.*, 2016; Svadlenak and Florea, 2025).

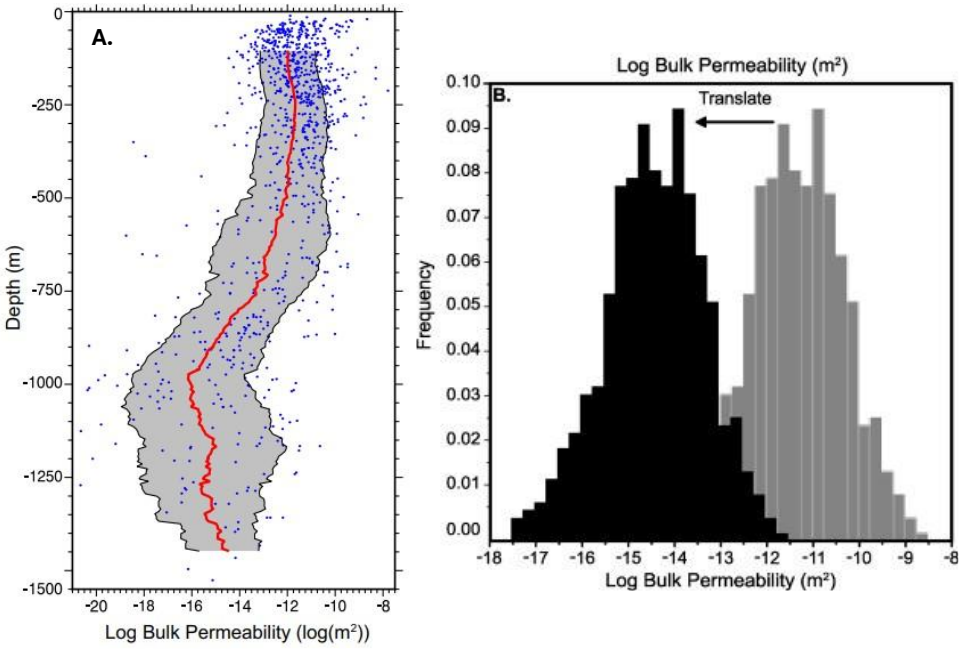


Figure 3. A) Permeability-depth profile with a 200 m average (red) and 1 standard deviation range (gray), with individual values from well tests (blue) (Jayne and Pollyea, 2018), and B) histogram of data compiled by Jayne and Pollyea, 2018, filtered to represent high permeability flow tops and shifted downward to represent permeability at depth >1 km (Jayne, Wu and Pollyea, 2019).

3.1.2 Bounding the Range of Uncertainty in CRBG LCOE

Figure 4 shows contour plots of CPG LCOE as a function of reservoir depth (y-axis) and transmissivity (x-axis) for two different temperature gradients of 35 C/km (top row) and 40 C/km (bottom row). The two columns of results are for brownfield development (left side) and greenfield development (right side). Brownfield development is defined as a CPG power plant which is developed at a pre-existing CO_2 storage site and greenfield development is defined as a CPG power plant developed a site without pre-existing CO_2 storage. We bound the inherent uncertainty regarding temperature, permeability, and flow top thickness at depth, using the red box in each subplot.

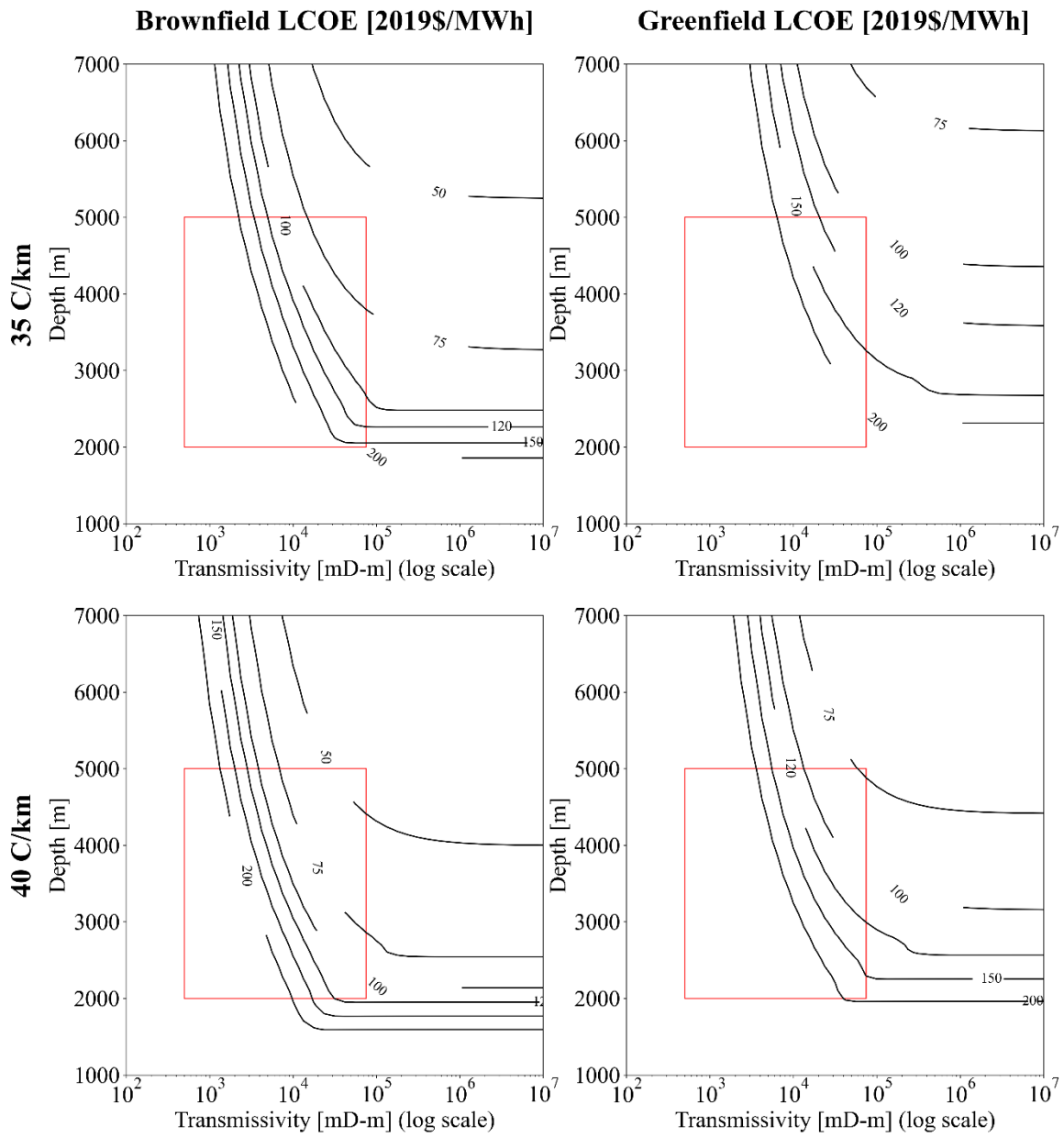


Figure 4. Levelized Cost of Electricity as a Function of Reservoir Depth and Reservoir Transmissivity. The geologic parameter space analyzed for the CRBG is shown as a red box in all subplots.

As shown by the size of the red boxes, there is a wide range of geologic characteristics within the CRBG and notably, it is within these bounds that the LCOE of CPG varies most substantially. For example, there are transmissivity, depth, and temperature gradient combinations that result in CPG LCOEs less than $50/MWh and above $200/MWh. As such, our results indicate that the CRBG may contain geologic conditions feasible for development of CPG if flow top injection zones can be identified with sufficient permeability and flow top thickness at depths of 2 – 5 km.

3.2 CO_2 Source Discovery

Figure 5 shows the geographic location of all CO_2 point sources in Idaho, Oregon, and Washington and Figure 5 displays the quantity of emissions from these sources, grouped by sector. As shown, there are ~39.8 $MtCO_2$/yr of capturable emissions from point sources, largely from power plants, refineries, pulp & paper, and minerals production sectors within a reasonable distance of the thickest portions of the CRBG to develop CO_2 transportation pathways. This quantity of CO_2 emissions could support between ~5.7 and ~20 MWe of CPG power capacity(Adams *et al.*, 2021) in the near-term, thus providing a sufficient amount of CO_2 to support CPG operations.

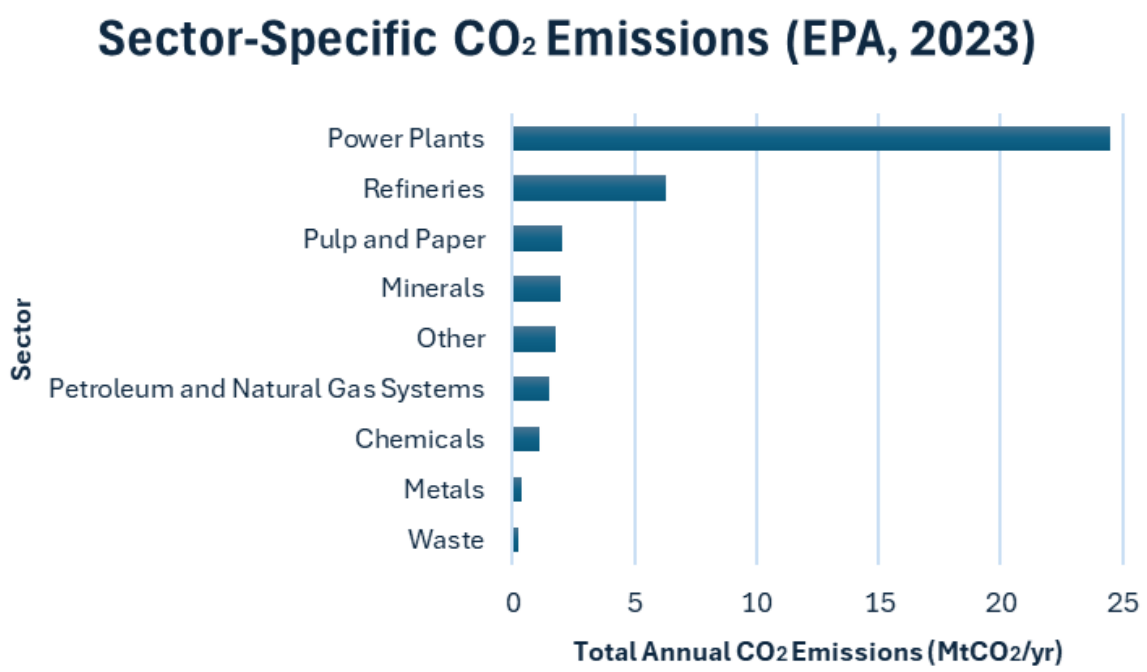


Figure 5. Quantity of CO_2 Emissions in the Pacific Northwest Region by Sector.

4 CONCLUSIONS

In this study we explored the potential for CPG power in the CRBG from both a geologic and CO_2 availability prospective. Following CPG operations, CO_2 mineralization (Schaef *et al.*, 2025) in the CRBG could deliver permanent long-term storage and reduce financial responsibility or post-injection site care requirements (and thus cost) compared to developing CPG in sedimentary basins where CO_2 trapping is dominated by physical trapping mechanisms like stratigraphic or residual trapping (Menefee and Schwartz, 2024). As such, exploring the potential for the CPG technology in basalt formations can provide substantial opportunities for both CPG and CO_2 storage. In conclusion, we found that:

- There are approximately 40 $MtCO_2$/yr of CO_2 from point sources located in the broader Pacific Northwest Region, which could enable upwards of ~20 MWe of geothermal power capacity.
- The cost of CPG in the CRBG could be between ~$50/MWh and ~$200/MWh. This uncertainty is driven by a lack of deep (>1 km) exploration wells.

These findings underscore the importance of drilling more exploration wells. Aquifer recharge from meteoric waters may mask deeper blind geothermal systems, and heat flow at depth may exceed estimated shallow geothermal gradients. Additionally, drilling deep exploration wells could also benefit both traditional geothermal and CPG development (Burns *et al.*, 2016), enabling regional efforts to develop geothermal resources.

Acknowledgements

Carbon Solutions acknowledges funding from the U.S. Department of Energy, Small Business Innovations Research program under award DE-SC0021570.

REFERENCES

Adams, B. *et al.* (2021) "Estimating the Geothermal Electricity Generation Potential of Sedimentary Basins Using genGEO (the generalizable GEOthermal techno-economic simulator)," *ChemRxiv Preprint* [Preprint]. Available at: https://doi.org/10.26434/chemrxiv.13514440.v1.

Adams, B.M. *et al.* (2015) "A Comparison of Electric Power Output of CO_2 Plume Geothermal (CPG) and Brine Geothermal Systems for Varying Reservoir Conditions," *Applied Energy*, 140, pp. 365–377. Available at: https://doi.org/10.1016/j.apenergy.2014.11.043.

Blondes, M.S. *et al.* (2019) *Carbon dioxide mineralization feasibility in the United States*. Available at: https://doi.org/10.3133/sir20185079.

Bryan, S.E. *et al.* (2010) "The largest volcanic eruptions on Earth," *Earth-Science Reviews*, 102(3–4), pp. 207–229. Available at: https://doi.org/10.1016/j.earscirev.2010.07.001.

Burns, E. *et al.* (2016) "Are the Columbia River Basalts, Columbia Plateau, Idaho, Oregon, and Washington, USA, a viable geothermal target?," *41st Workshop on Geothermal Reservoir Engineering, Stanford, CA*.

Burns, E.R. *et al.* (2011) *Three-dimensional model of the geologic framework for the Columbia Plateau Regional Aquifer System, Idaho, Oregon, and Washington*. Available at: https://doi.org/10.3133/sir20105246.

Cairncross, E. *et al.* (2024) "Nationwide Cost and Capacity Estimates for Sedimentary Basin Geothermal Power and Implications for Geologic CO_2 Storage," *Frontiers in Environmental Science* [Preprint]. Available at: https://doi.org/https://doi.org/10.3389/fenrg.2024.1422285.

Cao, R. *et al.* (2024) "Gigaton commercial-scale carbon storage and mineralization potential in stacked Columbia River basalt reservoirs," *International Journal of Greenhouse Gas Control*, 137, p. 104206. Available at: https://doi.org/10.1016/j.ijggc.2024.104206.

EPA (2023) *EPA FLIGHT 2023*.

Jayne, R.S. and Pollyea, R.M. (2018) "Permeability correlation structure of the Columbia River Plateau and implications for fluid system architecture in continental large igneous provinces," *Geology*, 46(8), pp. 715–718. Available at: https://doi.org/10.1130/G45001.1.

Jayne, R.S., Wu, H. and Pollyea, R.M. (2019) "Geologic CO2 sequestration and permeability uncertainty in a highly heterogeneous reservoir," *International Journal of Greenhouse Gas Control*, 83, pp. 128–139. Available at: https://doi.org/10.1016/j.ijggc.2019.02.001.

Johansson, L., Zahirovic, S. and Müller, R.D. (2018) "The Interplay Between the Eruption and Weathering of Large Igneous Provinces and the Deep-Time Carbon Cycle," *Geophysical Research Letters*, 45(11), pp. 5380–5389. Available at: https://doi.org/10.1029/2017GL076691.

McGrail, B.P. *et al.* (2014) "Injection and Monitoring at the Wallula Basalt Pilot Project," *Energy Procedia*, 63, pp. 2939–2948. Available at: https://doi.org/10.1016/j.egypro.2014.11.316.

McGrail, B.P. *et al.* (2017) "Field Validation of Supercritical CO_2 Reactivity with Basalts," *Environmental Science & Technology Letters*, 4(1), pp. 6–10. Available at: https://doi.org/10.1021/acs.estlett.6b00387.

Menefee, A.H. and Schwartz, B.A. (2024) "Quantifying the Value of Geologic Carbon Mineralization for Project Risk Management in Carbon Capture and Removal Pathways," *Energy & Fuels*, 38(6), pp. 5365–5373. Available at: https://doi.org/10.1021/acs.energyfuels.4c00138.

Millett, J.M. *et al.* (2024) "Lava flow-hosted reservoirs: a review," *Geological Society, London, Special Publications*, 547(1), pp. 357–387. Available at: https://doi.org/10.1144/SP547-2023-102.

Ogland-Hand, J. *et al.* (2022) "A Geospatial Cost Comparison of CO_2-Plume Geothermal (CPG) Power and Geologic CO_2 Storage," *Frontiers in Energy Research* [Preprint]. Available at: https://doi.org/10.3389/fenrg.2022.855120.

Porro, C. *et al.* (2012) "An Estimate of the Geothermal Energy Resource in the Major Sedimentary Basins in the United States," *Transactions - Geothermal Resources Council*, 36, pp. 1359–1369.

Schaef, H.T. *et al.* (2025) *Review of CO2 storage via in-situ mineralisation in mafic-ultramafic rocks*. Available at: https://doi.org/10.62849/2025-03.

Snæbjörnsdóttir, S.Ó. *et al.* (2020) "Carbon dioxide storage through mineral carbonation," *Nature Reviews Earth & Environment*, 1(2), pp. 90–102. Available at: https://doi.org/10.1038/s43017-019-0011-8.

Svadlenak, E. and Florea, L. (2025) *Groundwater chemistry in the Columbia River Basalt Group*.

Reidel, S. *et al.* (2013) *The Columbia River Flood Basalt Province*. Geological Society of America. Available at: https://doi.org/10.1130/9780813724973.