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Nationwide Assessment of Sedimentary Basin Geothermal Power

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ABSTRACT

We estimate the cost and capacity of sedimentary basin geothermal power plants across the contiguous United States. Sedimentary basins are ubiquitous, naturally porous and permeable, and the geothermal heat in these basins can be extracted with in-situ water or geologically-stored CO_2 and used to generate electricity. Despite this, the potential that sedimentary basins may have for generating electricity has been understudied. Here, we estimate the cost and capacity of sedimentary basin power plants across the contiguous United States on a 10 km by 10 km resolution using the Sequestration of CO_2 Tool (SCO_2T^{PRO}) geodatabase and the generalizable GEOthermal techno-economic simulator (genGEO). We find that the cost of sedimentary basin power is generally high (>$250/MWh) across the entire country and using CO_2 as the heat extraction fluid reduces the cost compared to using water. Depending on the financing assumptions and possibility of using wells drilled previously for CO_2 sequestration, the cost of electricity generation when CO_2 is used can decrease to ~$100/MWh, including in states not typically considered for geothermal power: Mississippi, Louisiana, and South Dakota. Overall, using CO_2 as the heat extraction fluid effectively doubles the portion of the sedimentary basin resource base that is amenable to power generation by "unlocking" resources that are either too thin, too cold, or that have insufficient reservoir transmissivity to support power generation with water.

1. INTRODUCTION

Sedimentary basins are naturally porous and permeable geologic formations and at least one, if not multiple, sedimentary basins underly approximately half the United States (USGS, 2022). These geologic formations are naturally full of geothermally-heated brine, but prior work has found the temperature of this brine to be too low to support electricity generation (Porro *et al.*, 2012). As a result, the potential that these geologic resources have for electricity generation is understudied. For example, the 2019 United States Department of Energy GeoVision study excluded sedimentary basins when estimating the electricity generation potential of the United States (USDOE, 2019).

While the temperature of sedimentary basin geothermal resources are generally low, prior work has found locations with high enough temperatures to support electricity generation (Banks and Harris, 2018). Further, it is also possible to generate electricity from these formations using geologically stored CO_2 as the subsurface heat extraction fluid instead of water, which is typically called CO_2-plume geothermal (CPG). With CPG, CO_2 that was previously sequestered is intentionally reproduced to the surface and used to generate electricity in a CPG power plant. Our prior work has demonstrated that CPG can increase power generation and decrease the cost of electricity compared to using water (Adams *et al.*, 2015, 2021). Further, using case studies of individual formations, we have also found that CPG could expand the geothermal resource base to locations not typically considered for geothermal power (Van Brummen *et al.*, 2022).

In this study, we continue investigating the potential of CPG by estimating the cost and capacity of sedimentary basin geothermal power plants across the United States. Specifically, we compare CPG power and power plants that use water as the subsurface heat extraction fluid (i.e., water sedimentary basin or "WSB" plants), considering both CPG brownfield (CPG BF) plants and CPG greenfield (CPG GF) plants within the analysis. CPG BF power plants rely on CO_2 injection wells previously drilled for CO_2 sequestration while CPG GF systems use new CO_2 injection wells drilled for power generation. Including both systems is important because our prior work demonstrated that brownfield development reduced the cost of power but it also reduced the generation potential because it limits the capacity to the number of wells previously drilled for CO_2 sequestration, which is less than would otherwise be drilled in a greenfield system (Ogland-Hand *et al.*, 2022).

This study is novel for two reasons. First, it is the first study we are aware of that compares WSB to CPG using a high-resolution database of sedimentary basin properties across the country. Second, we also demonstrate a new approach for conducting nationwide geothermal resource assessments. To estimate geothermal resource potential across large geographic areas, prior work have used methods reliant on volumetric equations with assumed recovery factors, or equations regressed from geothermal field data (Banks and Harris, 2018; USDOE, 2019; Pinchuk *et al.*, 2023). Here, we use a method that relies on thousands of simulations of a coupled reservoir-well-power plant model, each one optimized to minimize the levelized cost of electricity (LCOE). To our knowledge, this is the first study demonstrating that such a method can be applied to estimate a nationwide geothermal resource potential.

2. METHODS

Our prior work modified the Sequestration of CO_2 Tool (SCO_2T^{PRO}) to estimate the levelized cost of electricity (LCOE) of CPG using data generated from the generalizable GEOthermal techno-economic simulator (genGEO) (Adams *et al.*, 2021; Ogland-Hand *et al.*, 2022).

Here, we follow the same approach using genGEO data for water sedimentary basin power generation. Specifically, we use SCO_2T^{PRO} to estimate both the LCOE and power generation potential of CPG and of WSB across the United States in three steps:

1. We run genGEO across a large parameter space of geologic conditions that vary reservoir depth, temperature gradient, and transmissivity. The result of this step is a large parameter space of LCOE and power generation calculations calculated with process-level models coupling the reservoir with the well and the power plant, optimized to minimize LCOE for a power plant with a 1 km^2 area that uses 1 injection well and 1 production well (i.e., a “doublet”).
2. For a given set of geologic conditions, we use this large parameter space of results as a look up table and interpolate to estimate the LCOE and power generation. Here, we use a nationwide database of sedimentary basin properties that we developed in our prior work (Ogland-Hand *et al.*, 2023). This database includes reservoir permeability, porosity, net thickness, temperature, and depth on a 10 km x 10 km grid cell resolution, for over 2 million km^2 across the country. The result of this step is an estimation of the LCOE and power generation for a) CPG BF power plants; b) CPG GF power plants; and c) WSB power plants for every grid cell in the database.
3. Following our prior work (Ogland-Hand *et al.*, 2022), we scale the power generation up from step 2 because the genGEO data assumes a single doublet power plant system with a 1 km^2 area, but the area of each grid cell in the database is 100 km^2. As such, we multiply the power capacity results from step 2 by: a) the number of CO_2 injection wells also calculated with SCO_2T^{PRO} for CPG BF estimates; b) 78.5 for CPG-GF estimates; and by 100 for WSB estimates. We use 78.5 for CPG GF because this is the areal extent of CO_2 in the grid cells (Ogland-Hand *et al.*, 2022) and use 100 for WSB because 100 doublet systems with a 1 km^2 area can fit inside a 100 km^2 grid cell.

Lastly, the financing assumptions can change the LCOE of power plants by up to ~40% (Adams *et al.*, 2021). In this study, we continue to use the same three scenarios of financing assumptions as in our prior work (Ogland-Hand *et al.*, 2022), shown in Table 1. Please see our prior work for more information on how these assumptions are used to calculate LCOE.

Table 1: Financing Assumption Scenarios.

Financing Assumption	$LCOE_{CCS}$	$LCOE_{Ormat}$	$LCOE_{Lazard}$
Capital Recovery Factor [%/yr]	5.2	6.2	10
Fraction of Capital Cost Assumed for O&M [%/yr]	5.5	5.5	4.5
Capacity Factor [%]	95	95	85

3. RESULTS AND DISCUSSION

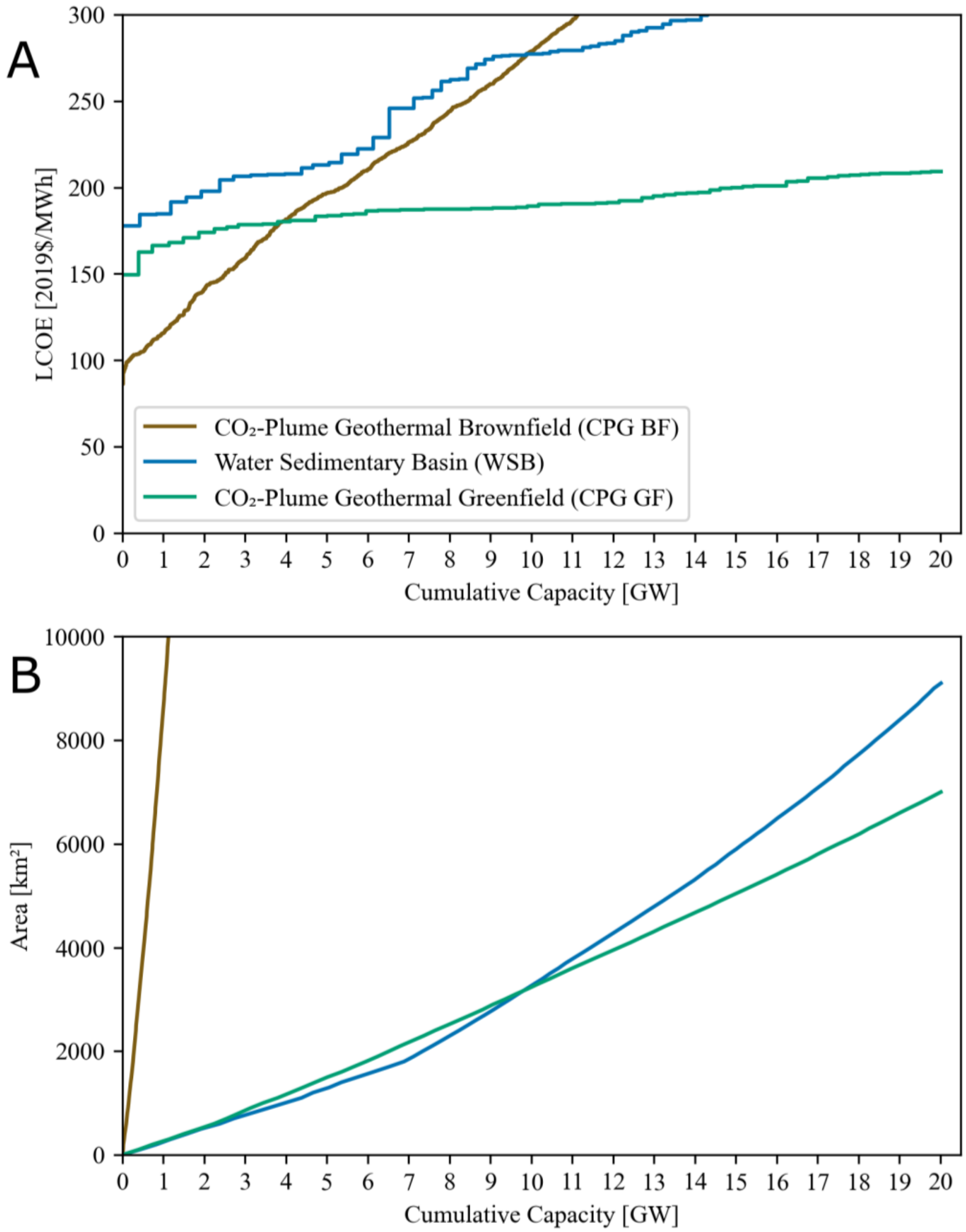

Figure 1: The LCOE of Geothermal Power as a Function of the Cumulative Power Capacity (A) and Area as a Function of the Cumulative Power Capacity (B). These results assume "CCS" financing assumptions (see Table 1).

Figure 1A shows the supply curve of sedimentary basin power across the United States and demonstrates that CPG technology can reduce the cost of sedimentary basin power for substantial amounts of capacity compared to using water. For example, CPG GF power is always lower cost than WSB power and there are approximately 4 GW of CPG GF capacity with lower cost and WSB power and CPG GF power. For context, as of 2021, the total geothermal power capacity in the United States was 3.6 GW (Robins *et al.*, 2021).

The reason the cost of CPG BF power increases at a faster rate compared to CPG GF and WSB in Figure 1A is because CPG BF systems use land less efficiently, as shown in Figure 2B. For example, to supply 1 GW of power capacity, CPG GF requires 300 km^2 of area while CPG BF requires 8,700 km^2 of area, a 29x increase. This difference occurs because the power capacity of CPG BF is limited to the number of wells drilled for CO_2 storage (Ogland-Hand *et al.*, 2022). In contrast, CPG GF capacities are higher because of the additional wells drilled for the purpose of generating electricity.

Figure 2 shows the LCOE of sedimentary basin power mapped across the United States for WSB power, CPG GF power, and CPG BF power. Comparing the WSB map to the CPG maps demonstrates that CPG technology can expand the geothermal resource base. For example, most of the sedimentary basin resource base in Illinois, Indiana, and Wyoming have insufficient reservoir transmissivity or temperature to support power generation (i.e., colored in black) when water is used but these locations become usable (i.e., not black) when CO_2 is used as the heat extraction fluid. At the same time, there are still many sedimentary basins that cannot support geothermal power generation using water or CO_2. For example, in Appalachia, Michigan, or Florida. As such, Figure 2 simultaneously demonstrates that CPG cannot expand the geothermal resource base to any location within a sedimentary basin.

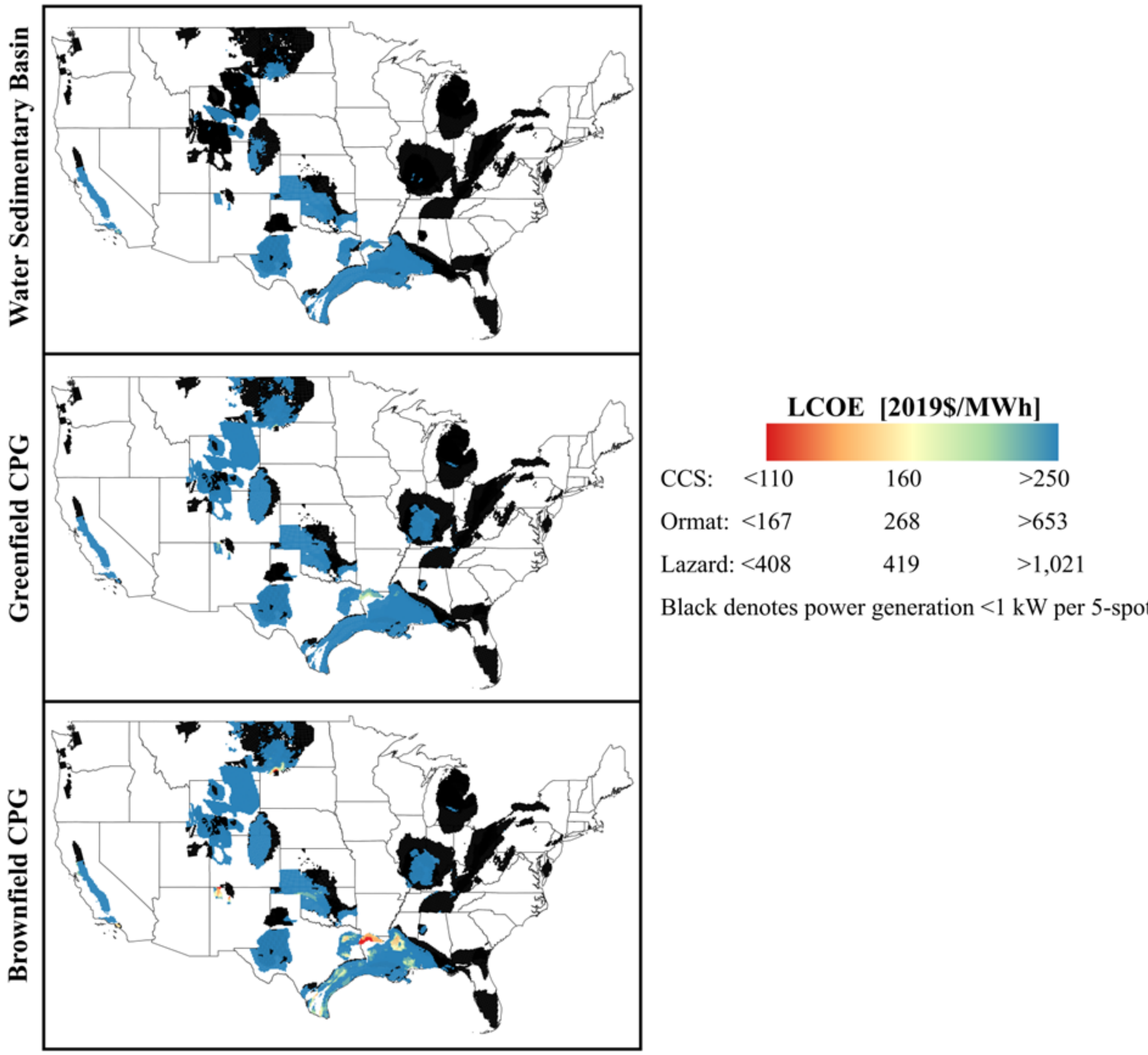

Figure 2: Geospatial LCOE of Sedimentary Basin Power.

While Figure 2 shows that CPG can "unlock" sedimentary basin resources that are otherwise unusable for WSB, the LCOE of the electricity is always high in these "unlocked" locations. In contrast, there are locations amenable to power with WSB but in which the LCOE of CPG, and particularly CPG BF, is much lower. Interestingly, these are largely locations not conventionally known for having geothermal resources amenable for electricity generation: Mississippi, Louisiana, and South Dakota (in addition to California and New Mexico, which have existing geothermal power plants (Robins *et al.*, 2021)). While the values of the LCOE are highly sensitive to the financing assumptions (Table 1Figure 2), overall, Figure 2 suggests the primary "unlocking" capabilities of CPG is not that it expands the resource base to locations otherwise unusable, but that it decreases the cost of electricity in locations in which the cost would certainly be too high for cost-competitive electricity generation (i.e., > $250/MWh).

Figure 3 shows the subsurface parameters for all sedimentary basins in the United States where each datapoint corresponds to a 100 km^2 grid cell: Figure 3A shows the subsurface parameters of all sedimentary basin resources where power generation is not viable for either CPG or WSB; Figure 3B shows the parameters for the resources where CPG power is viable but WSB is not; and Figure 3C shows the parameters for the resources where CPG and WSB power are viable. Each subplot also includes the percentage of total sedimentary basin resource in each category.

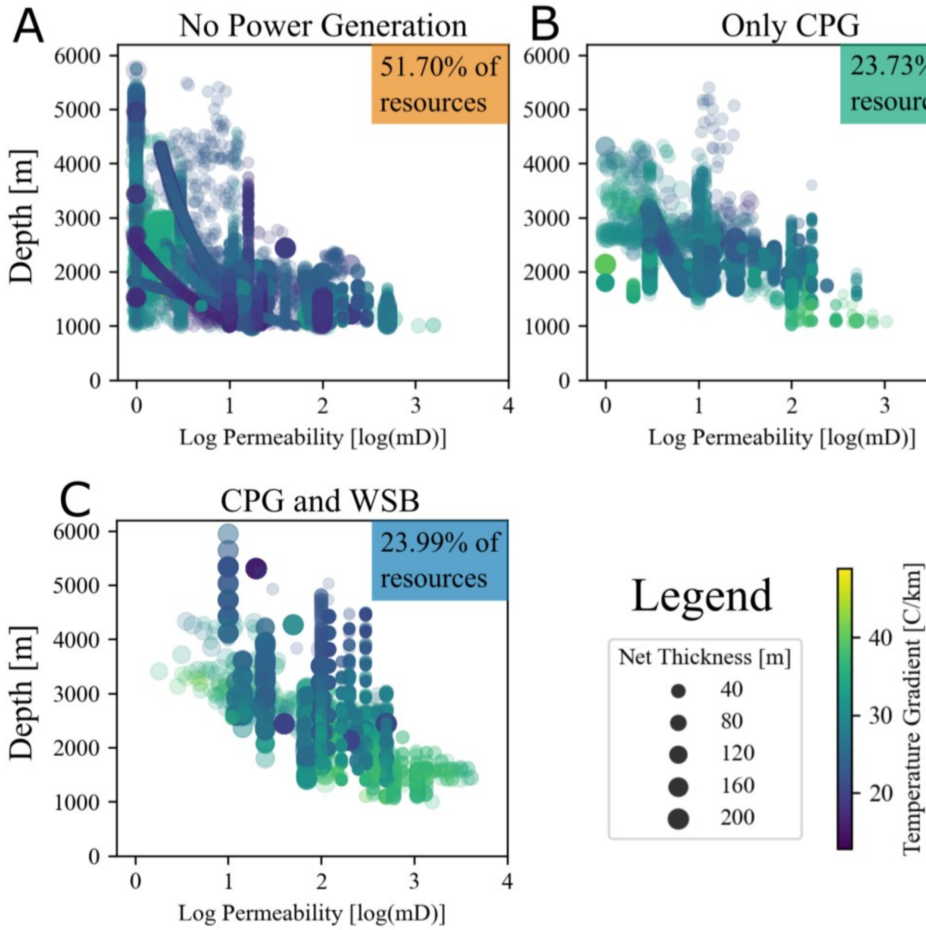

Figure 3:Geologic Properties of Sedimentary Basin Resources. Resources with higher temperature, depth, permeability, and thickness generally provide less expensive electricity, thus smaller and darker datapoints in the lower left of each subplot can be thought of as lower quality resources.

Figure 3 demonstrates why CPG "unlocks" portions of the sedimentary basin resource base, but not all areas not amenable to power generation, as discussed in Figure 2. First, Figure 3A shows that 51.70% of the sedimentary basin resource is not amenable to power generation (colored black in Figure 2). Compared to these geologic conditions, Figure 3B shows that the resources where CPG expands the geothermal resource base generally requires higher reservoir depth, temperature, and/or transmissivity, while Figure 3C shows that WSB requires these geologic conditions to be even higher. Overall, comparing subplots A, B, and C suggests that electric power generation is not possible in 51.70% of the resource base because of insufficient permeability, depth, thickness, or temperature. Also, comparing subplot B to C further demonstrates that CPG can "unlock" marginal quality reservoirs for geothermal power generation by enabling electricity generation in reservoirs that are either too thin, too cold, not deep enough, or with insufficient permeability compared to WSB.

4. CONCLUSIONS

In this study, we estimate the costs and power generation potential of both water and CO_2 plume geothermal power plants in sedimentary basins across the United States. We find that:

1. Across the country, the cost of sedimentary basin power is generally high (>$250/MWh) but there are locations with lower cost (<$150/MWh) electricity. The cost of CPG is always lower than that of WSB and states with the lowest cost CPG power include Mississippi, Louisiana, New Mexico, South Dakota, and California.

2. Developing CPG BF systems are less expensive than CPG GF systems but require more land for a given power generation capacity. As a result, across the country, CPG BF is only cheaper than CPG GF for about 4 GW of power capacity.

3. CPG technology effectively doubles the usable resource base for sedimentary basin geothermal across the United States by enabling power generation in reservoirs that are either too thin, too cold, not deep enough, or with insufficient permeability for WSB.

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