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Probabilistic Estimation of Levelized Cost of Electricity from Using Geologically Stored CO_2 for Geothermal Energy Production

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Abstract

The use of geologically stored CO_2 as a geothermal heat extraction fluid can take advantage of the beneficial thermophysical characteristics of CO_2 that can render it a more effective heat extraction fluid than the brine that exists in the aquifers. Some of these characteristics include a higher mobility (inverse kinematic viscosity) in reservoir conditions and a highly temperature-dependent density that can result in a naturally self-convecting thermosiphon between injection and production wells. This thermosiphon may reduce or eliminate the need for subsurface pumps—and the associated parasitic pumping power—for fluid circulation. Part of the utility of such a CO_2 capture, utilization, and storage (CCUS) system is the possibility to generate baseload or dispatchable electricity with levelized costs of electricity (LCOEs) that are on par with the LCOEs of other energy technologies of regional electricity systems.

Keywords: geothermal energy; sedimentary basin; carbon dioxide; geologic CO_2 storage; CO_2 capture, utilization, and storage; CCUS

1. Introduction

Two fundamental challenges for modern energy systems are to decrease carbon dioxide CO_2 emissions to the atmosphere and increase the deployment and utilization of renewable energy capacity. Doing so can decrease the rate at which CO_2 accumulates in the atmosphere, enhances the greenhouse effect, and exacerbates climate change. Carbon dioxide (CO_2) capture and storage (CCS) is one approach. The CCS process involves capturing CO_2 from point sources (e.g. fossil fueled power plants, cement manufacturers), compressing the CO_2, and injecting it through wells into geologic CO_2 storage reservoirs. Recent work has shown that geologically stored CO_2 can be used to extract geothermal heat, and that this heat can be converted into electricity in a direct CO_2 power plant [1]. In this process, which is sometimes referred to as CO_2 Plume Geothermal [2], captured CO_2 is injected through a well into a deep aquifer in a sedimentary basin geothermal resource, the emplaced CO_2 is heated as it flows through the reservoir and some of it is produced to the surface through a well. The energy is extracted from the heated CO_2 and converted into electricity, and the cooled CO_2 is then re-injected into the reservoir. In this work, we investigated the uncertainty of the levelized cost of electricity (LCOE) for using geologically stored CO_2 as a geothermal heat extraction fluid for electricity production. The results indicate that point estimates of LCOE conform to the median of the LCOE distribution, many of which may be dispatchable in electricity markets. Yet the distributions often have long tails toward high LCOEs.

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Nomenclature

LCOE Levelized Cost of Electricity

2. Methods and Data

We used an integrated process-level model of a direct CO_2 power plant, injection and production wells, and reservoir simulator to estimate the amount of net power that can be produced from such a CO_2-driven geothermal power plant [1]. This net power depends on the characteristics of the reservoir (e.g., geothermal temperature gradient, reservoir permeability, reservoir depth). In ongoing work these results were combined with cost estimates for geothermal energy production, geologic CO_2 storage, and elsewhere to estimate the LCOE of producing geothermal electricity with geologically stored CO_2 [3]. Given a range of parameters for geologic CO_2 storage reservoirs, we produced a reduced-form representation of the LCOE as a function of the reservoir parameters:

$$\boldsymbol{LCOE = \gamma_0 \cdot (\gamma_1)^{\kappa^N} \cdot (\gamma_2)^{D^N} \cdot (\gamma_3)^{T^N} \cdot (\kappa^N)^{\beta_4} \cdot (D^N)^{\beta_5} \cdot (T^N)^{\beta_6}} \qquad (1)$$

The independent variables in the regression are permeability, κ (mD), depth D (m), and the reservoir temperature, T (°C). These independent variables are normalized by "baseline" conditions $\kappa^N = \kappa/50$ mD, $D^N = D/2{,}500$ m, and, $T^N = T/102.5$°C. To produce distributions of LCOE, we conducted Monte Carlo draws for the confidence intervals for each estimated parametes under the assumptions that they are independent and normally distributed.

3. Results

Figure 1 shows an example of the LCOE distributions, for data from the U.S. Geologic Survey [4]. They are shown for a greenfield CO_2-geothermal development, where all of the costs for a geothermal power plant and a geologic CO_2 storage reservoir are considered, and a brownfield development, which assumes that the CO_2 storage operation exists and only the costs to add the geothermal facility and production wells are incurred.

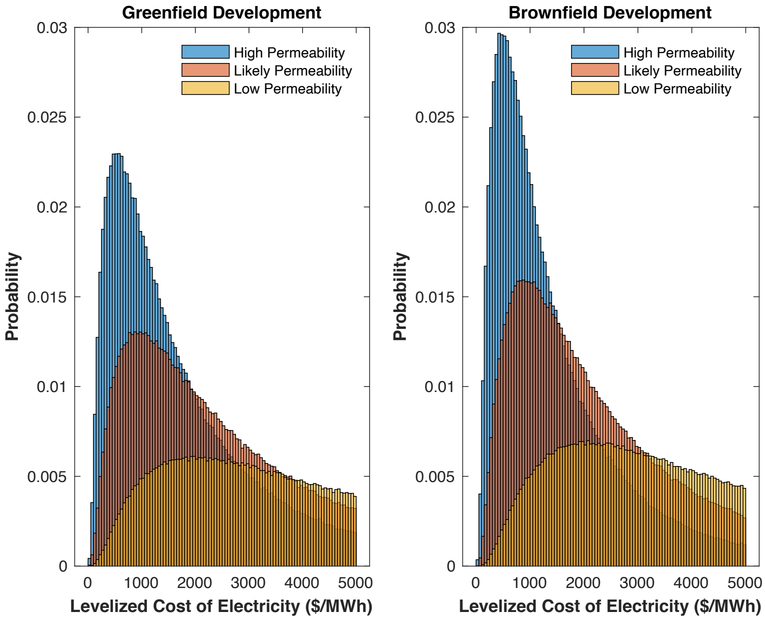

Fig. 1. Example distributions of LCOE for CO_2-driven geothermal energy production from geologic CO_2 storage reservoirs.

Given that reservoir parameters are uncertain, and often at best provided as ranges (e.g., 1 – 50 mD), the results indicate that there are ranges of geologic parameters where the median LCOE of the distribution is comparable with (point) estimates of the LCOE of other energy technologies. For example, there were never combinations involving a geothermal temperature gradient less than 30ºC/km with LCOEs <$500/MWh (e.g., Figure 1), but deeper (> 3km) and more permeable (e.g., > 100 mD) reservoirs often result in LCOEs that are on par with other baseload (e.g., nuclear) or dispatchable (e.g., natural gas) energy technologies [5].

4. Conclusions

The use of geologically stored CO_2 as a geothermal heat extraction fluid in a closed loop system that keeps the CO_2 isloated may provide revenue from electricity sales. This revenue may be useful in advancing the deployment of geologic CO_2 storage. Here, we built upon existing and ongoing work to estimate distributions for the levelized cost of electricity (LCOE) from CO_2-driven geothermal utilization in aquifers in sedimentary basin geothermal resources. We show that these distributions can contain LCOEs that are on par or better than those of other energy technologies, but often the tail of the distribution extends into LCOEs that are much higher than other energy technologies. These LCOE distributions are primarily determined by reservoir permeability, and there are combinations of geologic parameters that do not yield LCOEs that are equivalent or better than other dispatchable electricity generating technologies. For example, a geothermal temperature gradient of 20ºC/km geothermal temperature gradient, a depth of 1,500 m depth, or a reservoir permeabililty of 1 mD yielded distributions with little if any density where the LCOE was equal to, or better than, a the point estimate for a newbuild natural gas combined cycle power plant.

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