Optimal Geothermal Heat Extraction Using Carbon Dioxide that is Sequestered in Sedimentary Basins

Iti H. Patel[1], Jeffrey Bielicki[1,2], Thomas Buscheck[3], Martin O. Saar[4], Benjamin A. Adams[5]

[1]Department of Civil, Environmental, and Geodetic Engineering, The Ohio State University, Columbus, OH 43210, USA

[2]John Glenn College of Public Affairs, The Ohio State University, Columbus, OH 43210, USA

[3]Lawrence Livermore National Lab, Livermore, CA 94550, USA

[4]Department of Earth Sciences, ETH Zürich, Zürich, Switzerland

[5]Department of Mechanical Engineering, University of Minnesota, Minneapolis, MN 55455, USA

Abstract

Environmental and economic performance are interconnected, and CO_2 capture, utilization, and storage (CCUS) systems must consider both of these metrics when determining an optimal strategy for using a resource. Recent efforts have suggested that geothermal energy could be produced from CO_2 storage reservoirs that have a sufficient geothermal heat flux. Heated CO_2 can be produced to the surface, where the heat is extracted from the CO_2 and converted into electricity. With this process, profit can be generated from heat extracted from the reservoir, and the cold CO_2 can be re-injected into the reservoir. These CO_2-Plume Geothermal (CPG) systems rely on the temperature of the reservoir—and thus the temperature of the produced CO_2—but these temperatures can decrease if the rate at which heat is extracted from the reservoir exceeds the rate at which the natural geothermal heat flux increases the temperature of the reservoir. In this context, sustainability often considers the environmental performance of the reservoir. That is, the focus is on maintaining the temperature of the produced fluid at a desired level, but preserving heat in the CO_2 reservoir may not be economically sustainable.

We investigated the performance of a sedimentary basin geothermal resource that uses sequestered CO_2 as the heat extraction fluid (a CPG system). We developed and implemented a model, based on approaches from natural resource economics, to determine optimal strategies for generating a profit by extracting heat from a CPG system. We modeled the performance of a CPG reservoir, with CO_2 as the heat extraction fluid, using the Non-isothermal Unsaturated-saturated Flow and Transport (NUFT) code under a range of geologic conditions (i.e. reservoir depths between 2500m and 3500m, reservoir thickness of 50m and 100m, temperature gradients between 35C/km and 50C/km, and permeability between 10^{-15} m^2 and 10^{-11} m^2). These parameters cover a range of characteristics of sedimentary basins in the United States and, in fact, worldwide, and the simulations are limited to reservoir parameter combinations that have a levelized cost of electricity (LCOE) that is competitive with the LCOE of other energy technologies. For a given combination of reservoir parameters, the temperature of the produced CO_2 will change over time as a function of the initial amount of heat in the reservoir, the total amount of heat extracted from the reservoir, and the total

amount of heat that has flowed into the reservoir by conduction and advection. We combined the simulation outputs from all of the scenarios by normalizing (a) the temperature of the produced fluid by the initial temperature of the produced fluid and the temperature of the injected fluid, and (b) the amount of energy that is extracted from the reservoir by the amount of heat that could have been extracted from the reservoir. We then fit these normalizations to a generalized logistic curve to produce a reduced form relationship between these two parameters. This reduced form equation is an input into the natural resource economics model, which uses Bellman's Principle of Optimality to determine the time-path of the optimal mass flowrate to extract heat, given the profit that can be made and the natural rate at which the reservoir temperature renews. Our results suggest that the rate at which the temperature of the reservoir increases due to the geothermal heat flux is considerably smaller than reasonable discount rates. As such, the money that is generated from converting reservoir heat into electricity is greater than the rate at which the reservoir renews so that it is often optimal to draw down the temperature of the reservoir as quickly as possible in order to maximize the economic gain from the CO_2-geothermal system.

These results have important ramifications for systems that are seeking to generate profits from using large quantities of sequestered CO_2. While the profit that can be gained from the CCUS system may be substantial, it may be desirable to reap that economic gain as quickly as possible during the lifetime of the project. If CO_2 injection can continue after the majority of the economic gain has been derived, there may need to be further incentives to keep injecting CO_2 into the ground for long-term storage.

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