GRC Transactions, Vol. 43, 2019

Combining Geothermal Potential and Direct Air Capture for Negative Emission Power Generation in California

Hélène Pilorgé[1,*], Peter Psarras[2], Jiajun He[3], Jennifer L. Wilcox[1]

[1] Worcester Polytechnic Institute
***corresponding author: hpilorge@wpi.edu**

[2] Colorado School of Mines

[3] University of Illinois at Urbana-Champaign

Keywords

Negative emissions, direct air capture, geothermal energy, geothermal waste heat use, California

ABSTRACT

Since the Industrial Revolution, CO_2 emissions have grown exponentially, leading to atmospheric CO_2 accumulation and concomitant global warming. The IPCC special report (2018) estimates that the atmospheric temperature should not rise more than 2° if we want to avoid major consequences associated with climate change. This can be achieved by reducing CO_2 emissions through capture and sequestration, either at the emission point source or from ambient air. Direct air capture (DAC) technology answers the latter challenge but is to date hindered by high thermal requirements which effectively limit the net removal of atmospheric CO_2. One solution may exist in geothermal energy, which represents a large, low-carbon source of heat. This work outlines the potential of integrating DAC plants with geothermal power plants to optimize net CO_2 removal through use of a low-carbon heat source and minimize cost through exploitation of existing infrastructure. Full integration of DAC plants with all existing geothermal power plants in the contiguous U.S. could capture 12.8 $MtCO_2$/yr. Other options have been considered and include combining DAC plants with direct use geothermal or building new infrastructure near geothermal springs and wells. Following capture, reliable storage of CO_2 is vital to climate change mitigation. Several types of geological formations are suitable for long-term CO_2 storage in the pore space of subsurface reservoirs. The most mature technology to date involves sequestration in saline aquifers and depleted oil and gas reservoirs. This work will focus on California due to its leadership in strong environmental policy and abundance of high temperature opportunities. Several works have assessed reservoirs for CO_2 storage in California (e.g. USGS, 2013), through which minimum cost pathways may be defined for CO_2 sequestration. The result of this analysis is a cradle-to-gate economic analysis of DAC/geothermal plus storage options within the state of California.

1. Introduction

One of the biggest challenges of this century is to limit global temperature rise due to excessive anthropogenic greenhouse gases emissions to 2° by 2100 (IPCC Special Report, 2018). Adding to this challenge is our continued reliance on fossil fuel consumption in transportation, power generation, and industrial manufacturing. One solution to reduce the amount of atmospheric CO_2 accumulation involves carbon capture and sequestration (CCS), where CO_2 emissions are avoided at the point source. However, this solution is not applicable to all sectors. For example, though the transportation sector accounts for 28% of CO_2-eq emissions in the United States (EPA Report, 2019), emission points are too numerous and diffuse to treat with CCS technology.

Due to the dilute nature of CO_2 in air (0.04%) it lacks the driving force required to make its separation cost-effective. DAC technology approaches this challenge through the use of materials with a high capacity for CO_2 uptake though formation of chemical bonds that bind and remove CO_2 from air. The unescapable consequence of this strong initial uptake is the need for high thermal energy to liberate the chemically bound CO_2 and regenerate the capture media. This study outlines pathways to maximize CO_2 removal from DAC plants through integration of low cost, low carbon heat from geothermal energy facilities. Further cost reductions are achieved through the geographical optimization of DAC/geothermal plants with proximal CO_2 sequestration sites and the application of policy-based incentives. A case study on California shows the potential for this technology to be carbon negative when the captured CO_2 is then permanently sequestered into geological reservoirs.

2. Combining geothermal energy and direct air capture of CO_2

There are many factors to consider when siting a DAC plant, e.g. water use, proximity to storage, and cost of electricity. However, given the large thermal demand of DAC operations, it is logical to co-locate DAC plants with a reliable, low carbon (and low-cost when possible) heat source. The solid sorbent DAC process requires heat in the range 70-100℃ (NAS Report, 2018). Since this is the temperature range of exploitable waste heat, this is the technology used in this analysis. Detailed configuration of the solid sorbent DAC setup is available in the literature, e.g. NAS Report (2018), Gebald et al. (2011), Gebald et al. (2017), and Sinha et al. (2017). Geothermal energy has the potential to supply this heat, as the geothermal exit brine often reaches the required 100℃temperature required for solid sorbent regeneration.

In an integrated setup, waste heat is extracted from the geothermal fluid exiting the plant without affecting power generation. Geothermal is low-carbon source of energy, with an emission intensity of 45gCO_2-eq/kWh (Moomaw et al., 2011; Karlsdottir et al., 2011; Rule et al., 2009), making it particularly appropriate for DAC plant operation. In 2015, 2.3 GW of electricity was generated in the United States by 96 geothermal power plants (NREL Geothermal Prospector). All plant types are present in California, e.g. dry steam, flash, and binary plants, using a broad range of temperature for the working fluid used for power generation. The temperature of the geothermal fluid exiting a geothermal power plant depends on the temperature and the flow entering the plant, on the type of plant, and on the type of turbine used for electricity generation. Exiting fluid temperature is usually above 100° for flash plants, below 100° and often below 80° for dry steam plants and have an upper bound of 90° for binary plants, (DiPippo, 2005; Snyder et al., 2017; DiPippo, 2004). If the temperature of the brine exiting the geothermal power plant is below 100°, the DAC plant can still operate at a slightly lower efficiency for CO_2 capture

(Elfving et al., 2017; Bos et al., 2018). One way of reaching higher geofluid temperatures in dry steam plants would be to replace the current condenser by a DAC plant in the geothermal plant design.

All information about geothermal power plants including locations, conversion types, and power capacities is sourced from the NREL Geothermal Prospector. Steam or warm brine flow rates were estimated from the type of geothermal plant and its power capacity. Coupling DAC with existing geothermal power plants has the capacity to remove nearly 13 $MtCO_2$/yr in the United States, with a wide range of individual plant uptake from the $ktCO_2$ to the $MtCO_2$ scale (Figure 1). The total capital requirement to build a DAC plant associated with a geothermal power plant is about \$8M for a 10 $ktCO_2$ plant (Wilcox et al., *submitted*). The Federal tax credit 45Q supports CO_2 capture initiatives. In order to benefit from this credit, facilities have to capture more than 100 $ktCO_2$/yr. In the U.S. 35 DAC/geothermal plants would qualify for the credit, while the remaining 61 remain ineligible. Since the goal is non-intrusive integration of DAC with geothermal power plants, the plant design is not expected to change less a simple retrofit. Hence, this study outlines the potential for geothermal power plants to act as carbon-negative sources of energy.

Developing geothermal projects are currently at several stages of readiness in the U.S., from early exploration to under construction (NREL Geothermal Prospector). An analysis around California is presented to show future opportunities that could consider incorporating a DAC plant in their design (Figure 2).

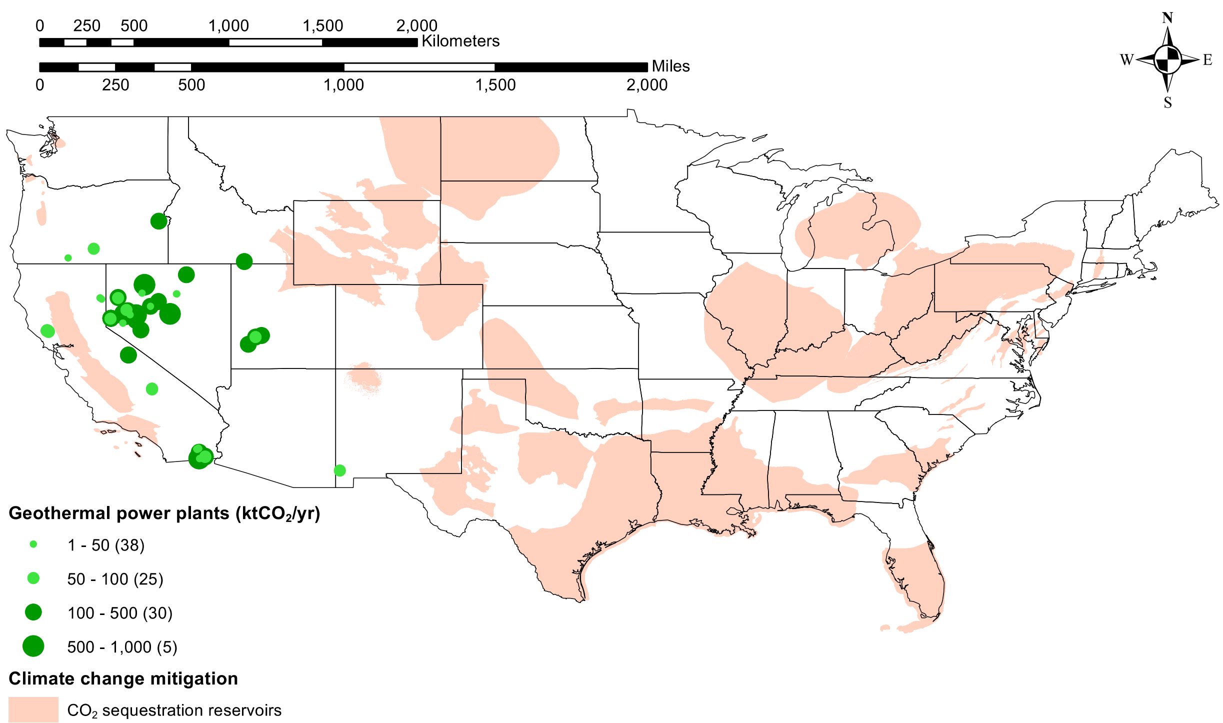

Figure 1: Potential CO_2 capture for DAC plants taking advantage of the waste heat from geothermal power plants. Dark green closed circles are the power plants that could benefit from the 45Q tax credit. Light green closed circles are the power plants that are too small to benefit from the 45Q tax credit. Light orange area are the geological sedimentary reservoirs assessed for CO_2 storage (USGS, 2013).

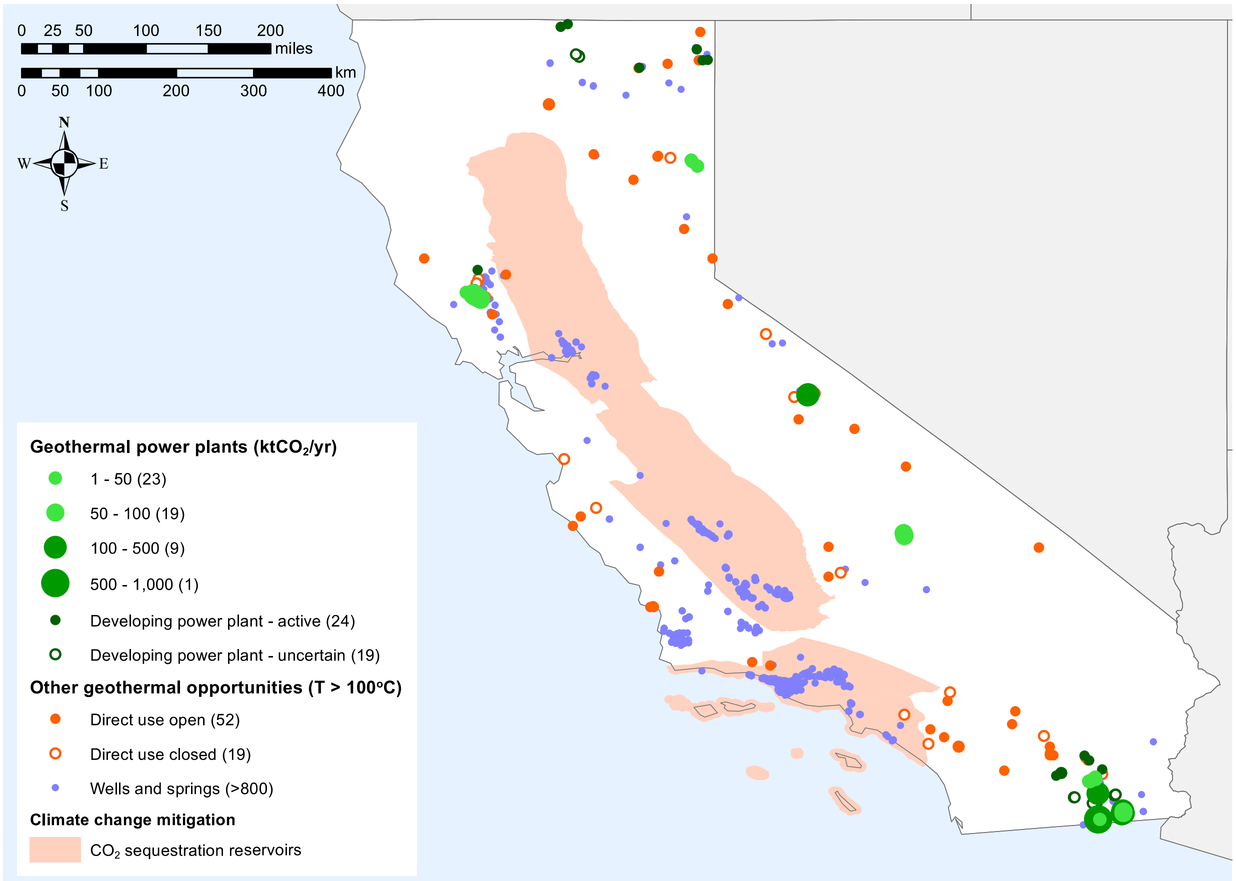

Figure 2: Opportunities for geothermal energy to power a DAC plant for climate change mitigation purposes. Legend is on the figure, for more details see the legend of Figure 1.

The heat from geothermal is also used directly for various purposes: space heating, greenhouse and soil heating, swimming pool heating, de-icing of parking lots and pavement, production of domestic hot water, air-conditioning, heat pump applications, assorted low-temperature washing, low temperature drying, and fish farming (Rybach and Kohl, 2004). Geothermal fluid pumped for direct use might be warmer than the minimal temperature required for the optimal operation of the direct use geothermal facility. In that case a DAC plant could be placed between the well and the direct use installation and use the geothermal heat without affecting the direct use geothermal facility. An analysis around California is presented, and for optimal sorbent regeneration, only the facilities with temperatures above 100° were considered (Figure 2; NREL Geothermal Prospector).

Using waste heat from geothermal power plants or direct use geothermal installations for DAC plant operation avoids the costly exploration and drilling of new wells. Nevertheless, considering existing springs and wells would add multiple opportunities for siting DAC plants. A data compilation of wells and springs with geothermal fluid temperatures above 100° in California is presented in Figure 2 (NREL Geothermal Prospector).

3. Geothermal energy as a path to climate change mitigation

DAC plants associated with geothermal energy facilities have the capacity to capture high amounts of CO_2. In order to be carbon negative, the CO_2 must be sequestered permanently in specific geological formations. Geological storage is expected to sequester 125 $GtCO_2$ by 2100 in order to meet climate goals, as outlined in the recent NAS Report (2018). In terms of technical readiness, the more mature technology involves sequestration within the pore space of sedimentary formations. The USGS have assessed saline aquifers and oil and gas depleted reservoirs across the U.S. for injection and sequestration of CO_2 (Figure 1; USGS National Assessment of Geologic Carbon Dioxide Storage Resources, 2013). These reservoirs have capacities from 0.23 $GtCO_2$ to 1,800 $GtCO_2$, with a total storage capacity of 2,740 $GtCO_2$ in the contiguous U.S.

Four reservoirs were assessed in California for CO_2 storage: Los Angeles, Ventura, Sacramento, and San Joaquin basins (Figure 2), with capacities of 3.7, 6.0, 29, and 51 $GtCO_2$, respectively (USGS National Assessment of Geologic Carbon Dioxide Storage Resources, 2013). Some of the existing and developing geothermal power plants, direct use geothermal facilities, and wells and springs with geothermal fluid temperatures over 100° are located on or close to these geological reservoirs suitable for CO_2 sequestration. The maximum collective CO_2 captured by DAC/geothermal plants in California is 4.5 $MtCO_2$/yr. Geological CO_2 reservoirs have the capacity to sequester way more than this amount of CO_2 during several decades. For that reason, multiple other geothermal facilities can be considered for the purpose of CO_2 capture and sequestration.

Moreover, pilot plant projects have been done for CO_2 sequestration in basalts, Gislason and Oelkers (2014), and ultramafic rocks such as peridotites are promising reservoirs (NAS report, 2018). Mafic and ultramafic rocks have the capacity to react more rapidly than sedimentary formations with CO_2 to form carbonate rocks, being even more secure for CO_2 sequestration. Outcrops of mafic and ultramafic rocks are distributed all over California, sometimes being closer to geothermal facilities than sedimentary reservoirs. When the technology for CO_2 sequestration in these rocks is ready, these reservoirs could be also considered, adding potential for CO_2 sequestration and climate change mitigation in California.

4. Conclusions

Operating DAC plants by taking advantage of the waste heat provided by geothermal facilities has the potential of capturing considerable amounts of CO_2. Being a low-carbon source of energy, integrated DAC/geothermal facilities could become carbon negative if the captured CO_2 is permanently stored. This would help to meet the climate goals set by the IPCC. We outline pathways through which California has the opportunity to be a leader in DAC and sequestration, in turn facilitating the development of projects in other favorable locations in the world.

Acknowledgement

The authors would like to thank Dr. Chad Augustine of the National Renewable Energy Laboratory, Dr. Charlene Wardlow, Geothermal Plant Manager for the California Department of Conservation, and Dr. Roger Aines, Energy Program Chief Scientist at Lawrence Livermore

National Laboratory for their helpful guidance and discussions on the geothermal pathways considered in this study.

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