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Abstract

Reductions in CO$_2$ emissions at a scale consistent with limiting the increase in the global average temperature to well below 2°C, compared to pre-industrial levels requires a range of measures, including increased use of renewable and low-carbon energy and reduced CO$_2$ intensity of fossil energy use. But each of these measures faces major deployment barriers. The variability of the predominant renewables (wind and solar) requires major advances in utility-scale diurnal and seasonal energy storage. Base-load low-carbon energy, such as nuclear, that cannot be cycled during periods of over-generation will have difficulty co-existing on electric grids with a large presence of variable renewables. Major deployment barriers for CO$_2$ capture, utilization, and storage (CCUS) in saline reservoirs include: (1) net cost (after accounting for utilization benefits); (2) water intensity of CO$_2$ capture, and (3) overpressure, which is fluid pressure that exceeds the original reservoir pressure due to CO$_2$ injection, because it drives key storage risks: induced seismicity, caprock fracture, and CO$_2$ leakage.

We present a synergistic approach to CCUS in sedimentary basins designed to address each of these deployment barriers. Our approach uses the huge fluid and thermal storage capacity of the subsurface, together with overpressure driven by CO$_2$ storage, to harvest, store, and dispatch energy from subsurface (geothermal) and surface (solar, nuclear, fossil) thermal resources, as well as excess energy from electric grids. Captured CO$_2$ is injected into saline reservoirs to store pressure, generate artesian flow of brine, and provide a supplemental working fluid for efficient heat extraction and power conversion (Buscheck et al., 2014; 2016). Concentric rings of injection and production wells (Fig. 1) create a hydraulic divide to confine the stored pressure, CO$_2$, and thermal energy below the caprock that overlies the CO$_2$ storage reservoir. This energy storage can take excess power from the grid and excess/waste thermal energy from thermal power plants, and dispatch that energy when it is demanded and thus enable higher penetration of variable renewables, while utilizing thermal energy that would otherwise be wasted. CO$_2$ stored in the subsurface functions as a shock absorber to provide enormous pressure-storage capacity and displace large quantities of brine, which will flow under artificially-created artesian pressure up production wells. Revenues generated by geothermal power and energy storage can cause CO$_2$ to become a valuable commodity to compensate for (or to exceed) CO$_2$ capture and storage costs.

We present a pressure-management strategy that diverts a portion of the produced brine once a target overpressure is reached at the injection wells. The target overpressure is that determined to be low enough to reduce the risk of induced seismicity, caprock fracture, and CO$_2$ leakage. Diverted brine is available for beneficial consumptive use, such as for power-plant cooling, or for generating fresh water using desalination technologies, such as reverse osmosis. This process, called enhanced water recovery (EWR), can be valuable in water-stressed regions. Our analyses indicate only a small portion (< 10%) of the produced brine needs to be diverted for the injection wells to remain below the target overpressure. Because the required recovery factor for desalination is relatively small (<10%), a wide range of brine composition can be amenable to economic treatment.
Our approach has several advantages over conventional (e.g., hydrothermal) and enhanced geothermal energy systems (EGS). CO$_2$ is a very efficient geothermal working fluid. Combined with the benefits of harnessing the overpressure driven by CO$_2$ storage and the greater lateral extent, permeability, and porosity of sedimentary basins, compared to hydrothermal upflows or artificially-created EGS reservoirs, it allows for greater spacing between injection and production wells. This efficient use of wells enables utilizing resources with lower temperatures than those of typical geothermal systems, which can increase geographic deployment potential. The addition of thermal energy storage (TES) further increases that deployment potential. The added benefit of bulk energy storage (BES) creates an arbitrage opportunity that can enhance economic viability. Our analyses show that BES achieved by time-shifting the parasitic load of pressurizing our system does not reduce the efficiency of driving fluid recirculation; hence our approach can be more efficient than other BES technologies. Because the primary cost of BES is that associated with oversizing the pumps for fluid reinjection, the capital cost can be less than that of other BES approaches. Moreover, the huge capacity of the subsurface can enable seasonal energy storage, while most other approaches are limited to diurnal storage.

For a range of reservoir conditions, we conduct a techno-economic assessment of our CO$_2$ earth storage concept. The next step for deployment is to find an operating reservoir, such as a CO$_2$ storage field project or a depleted oil or gas field, where there is enough information to develop a data-constrained reservoir model that can be used for design analysis and to gain more confidence in the viability of this concept.

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**References**


**Fig. 1.** CO$_2$ captured from a fossil-fuel power plant is stored in a permeable reservoir formation overlain by an impermeable caprock. Concentric rings of horizontal wells confine the pressurized CO$_2$ beneath the caprock. Stored CO$_2$ displaces brine that flows up wells to the surface where it is heated by thermal plants (e.g., solar farms) and reinjected into the reservoir to store thermal energy. Excess energy from electric grids or renewables (e.g., wind farms) is used to pump the heated brine underground.