

Reply to Juanes et al.: Evidence that earthquake triggering could render long-term carbon storage unsuccessful in many regions

Juanes et al. (1) offer three specific arguments in response to our finding that “because even small to moderate-sized earthquakes threaten the seal integrity of CO₂ repositories. . . large-scale [carbon capture and storage (CCS)] is a risky, and likely unsuccessful, strategy for significantly reducing greenhouse gas emissions” (2). We believe all three of their arguments are incorrect.

First, Juanes et al. (1) contend that, because most earthquakes in the Earth’s crust occur at depths several kilometers greater than that proposed for CO₂ repositories, their occurrence is not an indication of the likelihood of faulting in response to injection-related pressure increases. The opposite is true. In just the past 2 y, moderate-sized earthquakes in Texas, Oklahoma, Arkansas, Colorado, and Ohio have been related to injection of relatively modest volumes of wastewater (2, 3) in similar geologic formations at similar 2- to 4-km depths as proposed for CO₂ repositories. The critical state of brittle formations throughout the crust is why one of the three major findings of the recent National Research Council report on induced seismicity potential in energy technologies was that “CCS, due to the large net volumes of injected fluids, may have potential for inducing larger seismic events” (3). Triggered seismicity has been detected at several sites where small volumes of CO₂ have been injected into sedimentary rock at 2 to 4 km depth, including the In Salah field in Algeria. Seismicity triggered by fluid injection in brittle sedimentary rock at relatively shallow depths is a geophysical fact (3).

Second, Juanes et al. (1) argue that the existence of hydrocarbon reservoirs is prima facie evidence that buoyant fluids can be safely stored in the subsurface. However, pore pressure and stress evolve together in a hydrocarbon reservoir over long periods of time. When pore pressure increases too rapidly, it is relieved through faulting or hydraulic fracturing as a natural geologic process (4, 5). There are well-documented oil seeps

along faults observed at the sea floor in the Gulf of Mexico (5) and the Santa Barbara channel in California (6). Recent press reports describe gas leaks along faults in the North Sea*, and operations in Bohai Bay, China, where fluid injection induced a fault slip event that caused oil to leak to the sea floor†.

Finally, Juanes et al. (1) argue that site selection is the key to successful geologic storage of CO₂. As we originally noted (2), storage of CO₂ in limited volumes should be possible in geologic formations that are (i) porous, permeable, and laterally extensive to avoid significant pressure changes; and (ii) weakly cemented to avoid brittle formations that could release elastic energy through triggered earthquakes or aseismic fault slip events.

In summary, we agree that ideal geologic formations can be found for safe storage of limited volumes of CO₂ at depth. The purpose of our Perspective article (2) is to express reasons for concern about the widely held belief that CCS will be able to function at the extraordinary scale necessary for it to have a major impact on mitigating greenhouse gas emissions. There is ample evidence to suggest that triggered fault slip could render large-scale CO₂ storage unsuccessful.

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*www.eco2-project.eu/newsarticles/items/north-sea-fracture-discovered.html.

†www.conocophillips.com.cn/EN/Response/Pages/default.aspx.